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Guest editorial

Towards smart model-based governance by systems thinking

Introduction

In our role as Guest Editors, we are very pleased to present this special issue (SI) of Kybernetes, which is devoted to the following topic: “Towards smart model-based governance by Systems Thinking”.

The reason underlying this SI is the need to recognize how complex our world is and that this outlook entails understanding how to manage our organizations and design proper governance mechanisms accordingly.

Notably, complexity is not a buzzword; rather, it is a definite, strong and widespread feature of any modern system. This is because of a number of underlying factors, which have different natures (economic, social, environmental, political, organizational, etc.); generate short-, medium- and long-term consequences; and witness the interaction of multiple actors having personal (and often different) agendas and goals. A consequence of this situation is that complexity must be addressed and studied by relying on sound and proven tools and methodologies.

In addressing this issue, as clearly mentioned in the SI’s call for papers, our idea was to bring together two main streams of research that have been extensively studied, discussed and analysed not only by Kybernetes and all its distinguished contributors but also within the field of management studies: Cybernetics and Systems Thinking.

These two streams of research have a long history, and ample literature testifies to their breadth of application and their potentials in analysing various complex domains. However, although they are concerned with the same ultimate goal of assisting organizations and managers in dealing with complex systems and subsequently informing decision-making, Cybernetics and Systems Thinking have been developing along parallel paths towards their common goal even though they adopt different approaches.

Cybernetics and systems thinking

Cybernetics has its origin in the early 1940s and has been experiencing a long-term success because of the excellent work of scholars such as Norbert Wiener and Stafford Beer. Specifically, Wiener clearly emphasised that the term "cybernetics", at the time, represented a neologism that was invented to identify a new scientific field. As the author explains (Wiener, 1948, p. 14), this term:

[...] combines under one heading the study of what in a human context is sometimes loosely described as thinking and in engineering is known as control and communication. In other words, cybernetics attempts to find the common elements in the functioning of automatic machines and of the human nervous system, and to develop a theory which will cover the entire field of control and communication in machines and in living organisms.

The approach later expanded in breadth and also entailed a definite move towards social systems and softer sciences, and more specifically towards management science and governance issues (Beer, 1966; Jackson, 1987).

The Guest Editors are grateful to the Editor-in-Chief of Kybernetes, Professor Gandolfo Dominici, and to Professor Stefano Armenia for the continuous support and collaboration in creating, managing and publishing this SI. The Guest Editors are also thankful to all of the reviewers that provided valuable comments and insights during the various stages of the reviewing process.
Derived from a Greek word meaning “the art of steering”, Cybernetics relies heavily on two main pillars – the concepts of the feedback loop and self-regulation – which are actually shared with Systems Thinking.

**Systems Thinking** can be regarded as a field of study that aims to support people in their understanding that the systems in which they are embedded and take action are heavily interconnected and definitely complex; subsequently, they need to learn to use the approach of circular thinking rather than linear thinking. For this purpose, Systems Thinking provides a core set of tools (e.g. causal loop diagrams and systemic archetypes – see Senge, 1990) and focuses on mental models and on an individual’s ability to address problematic issues in complex systems (Richmond, 1993). In this regard, Systems Thinking should not be seen as a mere set of tools and methods when it is actually a philosophy that is rooted in the idea that we need a holistic approach to decision-making when living and operating in a complex and interconnected world (Meadows, 2008). Indeed, Systems Thinking advocates that we need to “understand that you can’t just do one thing and that everything is connected to everything else” (Sterman, 2000, p. 4).

This said, it is our opinion that the two previously mentioned streams of research share a common goal in supporting decision-makers as they carry out their decisions and take actions. This is absolutely relevant today, when modern organizations face complex issues, are active within multifaceted networks of interrelationships and have an enormous mass of data at their disposal to inform discussion and action.

**The building blocks of the special issue**

From the previous considerations, it is clear that complexity, availability of data and governance mechanisms are three key concepts that are addressed by both Cybernetics and Systems Thinking and, consequently, have been chosen as the main focus for this SI. In more detail, we sought out contributions that were able to study these three concepts further, adopting a triple perspective.

First of all, the SI looked for an in-depth examination of Cybernetics- and Systems Thinking-based projects, case studies and theoretical analyses in the following areas:

- people, technology and governance for sustainability;
- democracy, interactions and organisation;
- cyber-systemic thinking, modelling and epistemology;
- data-driven decision making vs model-based decision making; and
- modelling and simulation with Big Data and Smart Data.

From different angles and perspectives, this list of topics clearly includes the three concepts mentioned above.

Second, we encouraged authors to look at the list of topics keeping in mind that multiple levels of decision-making and governance may be present in our systems and may be chosen for their analysis or practice-based projects as well. To exemplify, we considered papers spanning from the individual to the global level, going through a number of other intermediate levels and perspectives (i.e. citizen/city, country, region and society).

Third, we were open to expanding the authors’ methodological choices for the articles and projects beyond “pure” Cybernetics and/or “pure” Systems Thinking, allowing for the use of methodologies such as system dynamics, agent-based modelling, discrete event modelling and simulation, as well as their “hybridizations” – specifically with the research area on “data-driven” (or Smart-data) decision-making.

Overall, we selected 11 papers which successfully went through a process of double-blind review and are now included in this SI. In particular, the SI is primarily linked to the BSLab-

As a final note, we emphasise that in launching the call for papers we have sought to involve academics and practitioners. At the end of this process, we believe that the SI effectively and successfully blends academic-based articles, as well as some rigorous practice-based contributions.

More details on the articles that have been selected and included in the SI are provided below.

Structure and content of the special issue
The structure of the SI is organized into two main parts. The first part includes three driving contributions, each representative respectively of the themes to which the SI is devoted: the complexity of world systems, cyber systemic methodology and Systems Thinking methodology. The second part includes eight contributions that develop studies on the topics which are the focus of the SI, the five areas mentioned in the previous paragraph. In this second section, three additional levels of perspectives are recognizable: individual governance of complexities, small/medium aggregations in the governance of complexities (i.e. society, city, country and regions) and global dimension governance of complexities (i.e. climate mitigation actions, 2030 sustainable development goals).

In the first part, the initial contribution is entitled “Governance through political bureaucracy: an agency approach” and represents a cross contribution between SI Area 1 (People, technology and governance for sustainability) and Area 2 (Democracy, interactions, and organization). The author approaches the theme of governance complexities, examining the role of political bureaucracy in policy development and implementation, pointing out that the policing process is not only an attribute of a political administration but also of the nature of its bureaucracy, which is complex and dynamic.

The second contribution, entitled “Governance for intelligent organizations: a cybernetic contribution” introduces a powerful model which has much to offer for organizational governance directed at the viability of organizations: viable system model. The model emanates from the tradition of Cybernetics, the science of communication and control of complex dynamic systems, which here is revisited, approaching the themes from Area 2 together with the Cybernetic methodology as seen in Area 3 (Cyber-systemic thinking, modelling and epistemology).

The third contribution in this first part, entitled “Improving managers’ intelligence through systems thinking” reports a general introduction of the Systems Thinking methodology approach, which aims to instruct managers to transform their organization into a learning organization that is able to figure out at least some future consequences of a manager’s decisions and actions. This contribution is primarily placed within Area 4 (data-driven decision-making vs model-based decision-making) because Systems Thinking is a model-based approach to decision making, and, in this case, the author proposes this methodology to satisfy governance requirements, as reported in Area 1.

Thus, within the framework of the previous three overview contributions, the Guest Editors are pleased to develop further detail in the second part of the SI, in which further important contributions are organized according to the social dimension of complex systems. This provides a crucial key for reading most of the existing systems of governance: individual governance; the governance of organizations formed by small/medium aggregations of individuals that have primarily a local impact; global dimensions of governance investing in larger communities; and the dynamic of planetary environments. In
each of these three dimensions, the principles and methodologies of Systems Thinking, Cybernetics and data analysis are applied to assist in decision-making.

Governance in an individual dimension is particularly evident in the following three contributions: “Meme propagation in the media sphere: a system dynamic model”, “Towards a systems thinking based view for the governance of Smart City ecosystem: a bridge to link technologies and Big Data” and “Smart technology and complex social issues of the Z generation”. Each article is aligned within the focussed topics of the SI. Nevertheless, each of them presents an original and a methodologically different approach to solving and satisfying the needs of individual decision-making.

The contribution “Meme propagation in the media sphere: a system dynamic model” is a study of how individuals and organizations can discern whether certain information broadcasted by mass media on the Web is propagated according to a natural interest (viral propagation) or whether the propagation is being forced by an intensive activity of advertising through a media bombardment. The study is based on big data analysis available from internet statistics in combination with System Dynamics methodologies, according to Areas 4 and 5 (Modelling and simulation with Big Data and Smart Data).

In the article “Smart technology and complex social issues of the Z generation”, the authors raise the question of how smart technologies are now influencing the self-organization behaviour of the Z generation. Smart technologies, such as mobile devices and the Internet, are furnishing a set of new tools that have changed the ways in which young people are being educated. Now the social system is more dynamic in terms of socialization, but the loss of personal contact with friends and family is seen as the main disadvantage of the improvements resulting from smart technologies. Both themes of governance and technology in Area 1 are highlighted, as well as the decision-making processes of Area 4.

In the third contribution, “Towards a system thinking based view for the governance of Smart City ecosystem: a bridge to link technologies and Big Data”, the authors explore the use of big data (Area 4) as applied to Systems Thinking (Area 5) for smart city governance (Area 1). The study points out that individual behaviours and decisions result from multiple influences. Here the relevant role of smart technologies aims to support the alignment among the different elements involved in a system by ensuring a fast reciprocal adaptation over time, together with the key role of Big Data as a pathway for building a strong feedback process that is able to increase the alignment between individual and aggregated behaviours.

Smart Technologies also are revolutionizing the interpretation and organization of aggregated systems. This fact is highlighted in the article, “Analysis of Crowd Stampede Risk Mechanism: A Systems Thinking Perspective”. Here, the authors report an interesting study on crowd behaviour in the case of sudden alarms or accidents, proposing a new System Dynamics modelling (Area 4) approach to manage, control and govern sudden emergencies (governance, Area 1).

Global water provisioning is also at risk of becoming an emergency because of a rapid increase in climate changes. In “Water used to be infinite: A Brazilian tale of climate change”, the authors analyse a case study of water scarcity in Brazil. Here the governance issues (Area 1) are approached mainly through System Dynamics methods (Area 4), presenting an integrative model for evaluating the resilience of a particular water supply system in a region of Brazil. Although there have been previous studies on this subject, the one included in this SI focuses on the role played by the water authority in facing a crisis, highlighting a specific combination of policies used to address an episode of crisis in a system that was unprepared for it. The theme of water scarcity is also treated in the article entitled, “A Systemic Methodology for the Reduction of Water Consumption in Rural Areas”, also situated
in a South American country, Colombia, where the effect of water scarcity is most evident. Here, the author also based the study on a System Dynamics approach, satisfying Area 4, by aiming to construct a technological solution (Area 1) in the field that needs the involvement of local communities (people, still Area 1) in the decision-making processes, in the design of the technology and in its construction.

Finally, two contributions focus on the global theme of sustainability. Sustainability represents a process that requires an accurate and complex network of actions to build an effective governance for the equilibrium that regulates human activities in their relationship with ecosystem boundaries. In the study “Sustainable Developments Goals – An analysis of the Outcomes”, sustainability is defined through the concepts of synergy, emergence, recursion and self-organization. Then, the authors developed an approach to help determine whether the efforts being made towards the Sustainable Development Goals could be expected to be effective. The results show that further public policies (Area 1 for governance) are needed for Brazil and for any other country that is willing to increase adherence to the SDGs. One of the ways in which it is possible to implement previous policy planning is presented in the contribution, “Integrated Simulation for National Development Planning” that proposes the Millennium Institute’s T21 model, (Area 4) a powerful tool to support planning in various countries. Here also the System Dynamics method is found to be a well-suited method for addressing the high level of dynamic complexity and the multidisciplinary nature of the issues.

After the brief overview of the building blocks that this SI concentrates on, the Guest Editors hope you enjoy examining these topics in greater depth.

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References

Further reading
Governance through political bureaucracy: an agency approach

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Abstract

Purpose – Smart governance ultimately relates to the ability of political administrations to elicit trust and public confidence. Political administrations normally generate rational policies that arise from their context-sensitive goals. The capability of an administration to develop and implement policies is measured as efficacy, which can influence the value and stability of an administration. However, policy development and implementation is not only an attribute of a political administration but also of its bureaucracy. The purpose of this paper is to explore the nature of bureaucracies, representing them as complex and dynamic.

Design/methodology/approach – A traditional blueprint model of a bureaucracy comes from Weber, seen to be a servicing body for the implementation of political policy decisions resulting from a process of governance. An alternative model arises from the fictional works of Kafka, which is underpinned by a firm conceptual basis of a bureaucracy that confronts that of Weber. Agency theory will be used to model bureaucracies, and comparisons will be made between the Weber and Kafka conceptualisation.

Findings – There are broad models of a bureaucracy that arise from different propositions such as a Weber and a Kafka model, the latter being more representative of administrations. Any attempts to measure comparative efficacy across political systems or administrations may well lead to failure due to the distinctions in the nature of the bureaucracies that they maintain. The paper argues that the Weber model is an unattainable boundary representation of a bureaucracy. In contrast, Kafka’s more pragmatic conceptualisation can be modelled as a pathological autonomous system that is both complex and adaptive. Such pathologies can be harmful to the implementation of socially improving policies.

Practical implications – The paper shows that even where a political administration has policy initiatives that can improve society, these can be corrupted and misdirected by its bureaucracy, mistakenly believed (by the administration) to be dedicated to the service of the administration, rather than the bureaucracy’s own self-interests.

Originality/value – No other approach has been able to graphically represent the relative natures of different bureaucracies, or their pathologies.

Keywords Bureaucracy, Weber, Cultural agency theory, Dynamic, Kafka, Political administration

Paper type Research paper

Introduction

Interest in this paper lies in modelling smart governance. Smart governance may be thought of as the combining of:

[...] digital technologies with innovative practices to improve government service delivery and citizen inclusion in developing and implementing policy. Used effectively, smart governance practices enable responsive, transparent and inclusive policy decisions that build citizen trust in government institutions at all levels, and create dialogue between supply (government) and demand (citizen) (IRI, 2015).

The inclusion of information technology facilitates improved and timely information that can contribute to political decision-making, while the other attributes constitute a social ethic.

Modelling smart governance requires an approach that is able to represent making and maintaining trust. The capacity of a political administration to elicit trust and public
confidence is determined by its capacity to govern (Citrin, 1974), and trust is also associated with its capability to deliver policy that suites perceived purpose. Such capability is often referred to as efficacy.

Political administrations are responsible for the governance of the domains that they are charged to oversee. They may be despotic or democratic, but in either case if they are to be viable (and hence adaptable and durable), they require both value and stability. Value is a public good, and stability is enhanced with substantive evidence of this good. Both may be enhanced where smart administrations support such facets as openness, transparency, accountability and evidence of governing efficacy, these being in contradistinctions to the development or maintenance of corruption. Corruption impacts on efficacy, and the two together are factors that contribute to the diminution of trust and public confidence. Efficacy and public confidence/trust in an administration’s capacity to govern are connected (Citrin, 1974; Schildkraut, 2011), and a loss of trust can result in disenchantment and political instability. These can of course be overcome through the use of steering media like money and power (Habermas, 1987).

Intentional governance normally arises through instruments of policy that are connected with a political administration’s context-sensitive goals. The capacity for policies to properly reflect goals and generate relevant outcomes can be measured on an inefficacy-efficacy scale. Here, efficacy provides illustration that an administration has the capability to generate and implement its goals effectively through policy instruments that (in a complex world) may require the coordinated (joined-up) participation of a plurality of autonomous units like departments. Consistent with the view of Huntington (1965), such complexity is the result of institutional development in the socio-political system being governed. Institutionalisation is the process by which a political system and its administrations and their procedures acquire value and stability, and increasing institutionalisation is often related to improved value and stability. In contrast, deinstitutionalisation is the process by which value and stability become degraded. For Parsons and Bales (1955), citing Huntington (1968), a political system can be defined in terms of its complexity, degree of autonomy and capacity for adaptability and coherence. Low levels of institutional complexity are often represented in terms of decentralised power held locally, this being responsible for piecemeal policy creation. Increasing institutional complexity is consistent with a centralised stage of political development, where power and policy is made centrally and then implemented. The development of power centralisation creates more coherence, as a single frame of reference is established for a given social domain. This contributes to a reduction in complexity because the ubiquitous application of the same meanings can occur. However, there is another form of power distribution referred to as distributed. When political systems “distribute” their power, they can improve on centralisation as it embraces the “local” advantages of decentralisation coupled with the advantages centralisation through a single frame of reference, where common meanings must be continually refreshed through intensive processes of semantic communication. However, sometimes, what appears to be a process of power distribution is really one of reverting back to decentralisation, determined by an analysis of the frames of reference adopted. For instance, the process of privatisation decentralises the power of social good management for social benefit, but there is a conflict of interest with corporate benefit in the frame of reference (Ogden, 1995; Boycko et al., 1996; Cornwall and Brock, 2005) that is ultimately unresolvable.

Policies are normally intended to facilitate, constrain or otherwise control socio-economic processes that occur in the domain of a governing body to the perceived advantage (however that may be defined) of society. In pursuing this, a political administration needs to adapt so
that its policies can be reflective of perceived changes in its dominion of power. Policies are also developed in accordance with the ideological orientation of the political administration holding power. Whether the political administration has a despotic or democratic governing body (independent of whether one is referring to a State or a Corporation), it will have some degree of transparently in its operations, this usually inversely related to its levels of corruption.

However, no matter what the nature of a political administration, it always requires one thing to help it develop and implement its policies: a bureaucracy. So, what is the nature of a bureaucracy, and what might be its relationship to a political administration that might offer increased value and an increase of institutionalisation?

The purpose of this paper is to examine the nature of governance with particular reference to the means by which policy initiatives are developed and implemented. The efficacy (Citrin, 1974; Madsen, 1987) of this policy process is, however, not just a function of the governing body, but also of its bureaucracy. In this introductory section of the paper, consideration is made of institutional processes of governance, the provision of an appreciation of the relationship between bureaucracies and political administrations, and the structured arguments that will arise to serve the paper’s purpose. In the rest of the paper, deeper consideration will be made of the nature of bureaucracy and its relationship to the political administration that it services. As part of this, the paper will explore the dynamics of political bureaucracies. It will do this through a modelling approach referred to as Cultural Agency Theory (Yolles, 2009). This is a cybernetic “living system” structuring approach in which social organisations are perceived to be complex adaptive systems portraying the characteristics of living systems.

**Bureaucracy and political administrations**

The vision by Weber (1947) of a bureaucracy is that it provides an uninvolved supporting administration for the implementation of policy. The vision is flawed, however, as according to Eckhard and Ege (2016), there is a general consensus in the literature that bureaucracy influences policy-making, but in a variable way.

This can be explained by Downs (1964) who has developed a theory of bureaucracy that sits on top of Weber’s (1947) original conceptualisation. It explains their issues of poor communication, message corruption and the distortion of directives that arise in the hierarchical structure that bureaucracies usually embrace, and the dynamics that they possess that actually do develop and change. Such conceptualisations were never an element considered by Weber to have significance in his vision of a static administrative body that would always perform efficiently in its implementation of political decisions.

Political decisions are an attribute not only of state bodies as they pursue their processes of governance but also of any organisation in which decisions are made and implemented within a complex social setting. Administrative bureaucracies are designed to service political decision-making, and as such it might be argued that all administrative structures are representative of bureaucracies. This can be so argued when a bureaucracy is seen as a social subsystem of administrative structure that functions within a given frame of reference, and that has a set of regulations in place to control (rationalise, facilitate implementation and professionalise) activities to deliver services on behalf of some policy directive delivered through corporate or state governance. In this paper, this definition will be deduced from the literature, and its consequences considered in the light of the different perspectives of Weber (1947) and Kafka (1926) concerning the nature of a bureaucracy. While these perspectives might be considered to be two diametrically opposed and hence un-relatable, it will be argued that their positions can be connected though work like that of
This sees bureaucracies in terms of human dynamic systems that have the capacity to move the Weberian idea of an ideal static organisation towards the Kafkian idea of an organisation that is anti-pragmatic being dislocated from the reality. This view is supported for instance, by Lizhi’s (2016) tales of Chinese bureaucracy. Any attempt to compare Weber with Kafka may be argued to be futile, as the former work is conceptual, while the latter is fictional. However, while Weber’s work is explicitly constituted as a conceptual design for a bureaucracy, Kafka’s has embedded within it an implicit conceptual design that can be extracted, allowing comparisons to be made. A return will be made to this shortly.

Bureaucracies service the needs of political systems operating with some form of legitimate governance, that is where the acts of governance conform to the principles of accepted law. An ideal for such bureaucracies is usually seen in the light of Weber’s (1947) conceptualisation: a purely rational organisation that operates in a way that has some connection with the positivist idea of an efficient machine. However, pragmatic questions have been raised (Blau and Scott, 1962; Grigoriou, 2013; Ivanko, 2013; Jørgensen, 2012) about the validity of the rational bureaucracy model, as bureaucracies are run by individuals who have their own perspectives, orientations and their culture or way of doing things.

Whatever the nature of a political regime and its processes of governance, there is normally an administrative bureaucracy there to serve it. Having connected the words administration and bureaucracy, it is useful to distinguish between them. For Livioara (2010), an administration is usually associated with an institution that has a social system that fulfils its tasks. The institution is normally defined as a stable valued recurring pattern of behaviour operating under some sort of political governance. In contrast, a bureaucracy is a social subsystem of administrative activity that functions within a given frame of reference. The functionaries that populate a bureaucratic system and help to formulate and then implement policies for governing processes do so according to a strategic brief. However, might their perspectives cloud that brief? If there are commonalities among the personalities that create bureaucratic norms, does a bureaucracy therefore maintain its own culture that is distinct from that of a given political regime? If so, how if at all does this impact on the “effectiveness” or the “efficiency” of the implementation of political policy decisions delivered by governance?

To respond to such questions, one must be clear not only about what a bureaucracy does but also about its very nature. The State bureaucratic arena involves the formulation and implementation of policy. The regulation and delivery of services and governance through bureaucracy is an important determinant for social and economic development (Hyden et al., 2004). For Grigoriou (2013, p. 1, citing Dimock, 1959), bureaucracy can also be seen as “the administrative structure and set of regulations in place to control (rationalise, render effective and professionalise) activities, usually in sufficiently large organizations and State government”. It should be noted that by the term “render effective” is meant “to facilitate implementation”, rather than referring to any form of effectiveness in activities, which unlike efficiency is not part of Weber’s conceptualisation. Grigoriou notes that there is a degree of efficiency that is in part a function of the environment in which the bureaucracy operates. It may also be seen to be a function of its own internal conceptual capability to help develop and implement policy. However, this latter statement makes an assumption that a bureaucracy may vary away from the pure rationality idealised for it by Weber, implying that functionaries have cognitive and emotional capacities that vary with context and may create divergence from some pure rationality, a notion that will be revisited.

A political bureaucracy is intended (for Weber) to serve policy-making functions. However, it is conceptually unimportant if these are for the governance of a State or a
Corporation, as both have regulations that apply to their respective memberships. As such organisational bureaucracy is explained by Fayol (1918, p.6, cited by Livioara, 2010), who says:

[...] there is no doctrine of private business administration and a separate one for the State affairs: the administrative doctrine is universal. The principles and general rules that apply to business are useful to the State administration and vice versa.

This begs the question of how the natures of the State and Corporation may be related. Adapting a definition by Grigoriou (2013), the nature of the State is politically and institutionally organised body of people inhabiting a defined geographical entity with an organised legitimate government, which may also be referred to as a governing executive. It is an outgrowth of society with its origin coming intrinsically from society, and is the result of a contract between the stakeholders of that geographical entity and the executive established to serve and develop their interests and ensure their liberty. The stakeholders in the State system are normally its citizens. In ancient Greece, there were two grades of stakeholder, the primary stakeholders called citizens who had the social power of a democratic role, and secondary stakeholders called slaves who only had the personal power of obligation to their masters to perform required work.

A related definition can also apply to a corporate organisation, which may be seen as a politically and institutionally organised body of people inhabiting a defined geographical and purposeful entity with an organised legitimate executive. It is an outgrowth of society and has an intrinsic or extrinsic societal origin, and is the result of a contract between the stakeholders of that geographical entity and the executive established to serve and develop their interests. Primary stakeholders and secondary stakeholders may be identified whose benefits are differentiated. The former usually has a citizen’s democratic role with social power to contribute to State decisions, while the latter may only have personal power through the obligation to perform work. In a hierarchical structure, the latter may be a despotised employee.

In other words, the State and the Corporation both serve stakeholder interests. However, in some cases, executive governance becomes pathological, where for instance the interests of its executive become directed towards the self-production of elements of itself, rather than the interests of its stakeholders. In this case, the executives and their extended kinship usually become the primary stakeholders. As such pathological geographical entities may be seen to be corrupt and unethical. An illustration is the State Government of North Korea which Transparency International indicates to be one of the most corrupt countries in the world (TI, 2014), while Corporate Enron has a reputation of being one of the most well-known highly successful corrupt companies until it was collapsed (Whittington et al, 2003). In this illustration, the frame of reference used that enable a North Korea and Enron to be related is corruption.

However, it is also possible to consider a frame of reference in which services in Corporate and State entities are the same. One such illustration is the residential homes for the elderly. These may be seen as bureaucracies that administer care for elderly patients. Their function is to administer care for residents, the functionaries being management, health workers like doctors, nurses and auxiliaries. The functionaries normally operate in power-centred hierarchical structures and activities operate through a set of regulations that control (rationalise, facilitate implementation and professionalise) the activities to deliver services on behalf of some policy directive delivered through Corporate or State governance. An executive provides governance for the care residences, though the regulations that residences abide by must conform to
State regulation. Whether a home is Corporate or State owned, the stakeholders include such as staff, patients and the families of the patients. In the case of corporate homes, primary stakeholders are shareholders. In the case of State homes, there is a supersystem bureaucracy (to which homes are attached) at work that constitutes the primary stakeholder. In this case, supersystem bureaucracies may be seen as political authorities for the subsystem bureaucracies that they govern. Other distinctions between Corporate and State residences for the elderly demand answers to the following questions:

Q1. Who pays for the resident patients (the State or private individuals)?

Q2. Who are the stakeholders to which the surpluses from accrued revenues go (the State of corporate shareholders)?

Q3. What degree of participation in decision-making in relation to residents do the families of patients have?

In response to the last question, participation in decision by residents or their families tends to be limited in power-centred hierarchies. Quality of care should be high, but internal failures through the creeping-in of unidentified errors within a strong hierarchic structure can be deadly (Cohen, 2013). Another feature of homes, whether corporate of State owned, is the need for the participation of residents (in cases of resident incompetents, through the families) in decision issues involving them, but this is often missing in hierarchical organisations that are centred on their internal processes, often with unfortunate results (Sobis, 2013).

Developing an argument
Weber’s (1947) model of a bureaucracy is often seen as an ill-conceived starting point, especially when comparing it to the perspective of Kafka (1926). The Weberian model is seen as a theorised “ideal” blueprint of a bureaucracy that, for Jørgensen (2012), could function well if people were not involved. This is because it is a simple purely rational entity that effectively constitutes a mechanism (like a clock) that does not admit the complex reality of individual cognitive and emotional processes by those who make it function – its functionaries (as cogs). In contrast, the Kafka model is an untheorised model that arises from experiences of anonymous and not-so-anonymous threats, for instance by his father. However, an inherent model has been extracted by Jørgensen (2012) – based principally on Kafka’s defining work The Castle, and while fictional it has inherent within it the principles of an administrative and organisational model. It may also be seen as a possible “pragmatic” outcome of the Weber model when people become involved, taking it far from the ideal blueprint because of the introduction and nurturing of fundamental pathologies.

To reflect the distinction between the ideal and the pragmatic models of bureaucracy, two representations will be offered. The first describes it as a rational rule-based servant intended to service the needs of governance, while simultaneously regulating the exercise of its political power. Second, with exposure to real human environments, it develops dynamically to become an autonomous system in partnership with a political system, but becoming subject to pathologies that, like its symbiotic political system, can make it power centred.

The dynamics of political bureaucracies
For Jørgensen (2012), Weber’s idea of the bureaucratic organisation is characterised by the following attributes:
Authorisation to make decisions is established in rules.

Functionaries are placed in a **hierarchical** system, and they operate with a high degree of specialisation.

Functions are performed through the use of documentation.

The public and private lives of the functionary are strictly separated.

The functionary has been professional/academic trained.

Holding office by a functionary is a full-time job giving a salary that constitutes the prime source of income.

Jørgensen recognises that Weber’s model of bureaucracy is an **ideal** type of analytic tool for policy implementation that represents the development of certain features of reality, but these never can be fully realised. It controls the relationship between the societal stakeholder and administrative authority and regulates the exercise of political power (Jørgensen, 2012).

Ivanko (2013) notes that Weber’s idea of a bureaucracy supposes that the members of a (State or Corporate) organisation should maintain strict observation of its rules at all of its levels of operation. Additionally, competences and responsibilities must be clearly delimited and the basis of mutual actions must be impersonal relationships. There also needs to be a division of labour in which highly specialised tasks create a chain of command so that tasks are performed in a predefined way. In addition, the organisation operates in a hierarchical way creating a bureaucratisation of relationships. Ivanko (2013) also notes that there is a reasoning for this type of organisation: Weber (1947, p. 337) believed such a bureaucratic organisation is machine-like and is therefore technically superior to any other form of organisation. In contrast, Blau and Scott (1962) note a danger: that in a bureaucracy, if free men become mere cogs in bureaucratic machines, they create one of the greatest threats to social liberty, a notion explained by Blau (1956, p. 60). He defines a bureaucracy as a type of organisation designed to accomplish large-scale administrative tasks through administrative efficiency. The administrative tasks might include the formation, implementation and servicing of political executive policy. The efficiency, which facilitates optimal functionality and therefore assumes full knowledge of the issue surrounding the implementation of the large-scale administrative tasks, is deemed to arise because a bureaucracy systematically coordinates the work of many bureaucracy functionaries, using specialisation, a hierarchy of authority, a system of rules that are not constructed by the bureaucracy and impersonality thereby insulating bureaucrats from the accusation of partiality towards policies or ministers. By its very nature, Blau tells us, it needs to be controlled by democratic processes if it is not to enslave society.

Jørgensen (2012) compares Weber’s ideal bureaucracy to Kafka’s (1926) more inherently pragmatic model. He argues that while some regard the two models as quite distinct (and thus incommensurable and incomparable), this is not the case. Rather, the former is an ideal static model, and the latter a pragmatic dynamic one. Here then, attributes of a Weberian bureaucracy may be lost in due course after it has become exposed to pragmatic issues, and the two models merge when exposed to reality. While in Weber’s ideal bureaucracy there is a strict separation of public and private lives of the functionary, for Kafka it is difficult for them to always be so separated. Documentation, which is a central feature, is not always properly administered. Emotions are also involved, as are power struggles, and illegitimate (for Weber) passion. Another attribute is the system of rules, which for Weber should be transparent but which for Kafka are invisible and inaccessible. While a bureaucracy is intended to mediate in the use of political power, in the Kafka model such power can be
transferred to the bureaucracy, a situation which Weber’s ideal model would not admit. In line with Jørgensen’s (2012) representation of Kafka’s model, Livioara (2010) considers power extensions to a bureaucracy that impact on the capacity of a political system to create and implement policy, and these can include:

- **Intensification** of intervention in the socio-economic life, due to the increase in the volume of activity.
- **Growth** in complexity governance and in the need for technical expertise due to social complexity technological development, leading to a greater power of bureaucracy.
- **Manipulation** of elected officials by bureaucratic functionaries through direct guidance by their experts.
- **Limited resources** for elected officials in comparison to the bureaucracy, allows the bureaucratic functionaries to dominate the resolution of issues.
- **Change** of elected officials as opposed to the permanence and continuity of public servants, creating weakness of the former due to the latter’s experience and knowledge of problem diversity.

Another attribute of a Kafkian bureaucracy is the inbound development of its hierarchy, where “endless hierarchies without top or bottom cause unpredictability, a preoccupation with formal positions, and a ‘verticalization’ of language and sense of reality” (Jørgensen, 2012, p. 204).

Jørgensen also notes that the Weberian model is an artificial one that is ruined by people when implemented. In concert with Blau, he explains that it then becomes difficult to introduce controls that are able to regulate subjective, emotional and interest-driven control of others, characteristics that can develop as pathological traits. Thus, documents and role positions may become symbols of personal significance resulting in too much abundance in documentation and hierarchy. These can create a need for personal connections, beneficial occasions and personal services, and these can result in the loss of distinction between public and private life. Such attributes are counterproductive and self-reinforcing. Jørgensen (2012) further notes that such exaggerated bureaucracy creates excessive regularity leading to dysfunctional irregularity.

What Jørgensen (2012) calls an exaggerated bureaucracy is referred to by Livioara (2010) as an *excessive* bureaucracy. To understand this, it is useful to recall that Livioara defined a bureaucracy as social subsystem of administrative activity. This subsystem has a number of issues that together create a succinct description of the inherent ailments of Weber’s blueprint. These include its incapacity to adapt due to its adherence to rules, and its indifference to outcomes of its activities; its incompetence; its inflexibility; its irresponsibility; its inhumanity which is harmful to democracies; its economic efficiency and its individual freedoms. In sum, a bureaucracy is a simple, legalist and authoritarian society (Olsen, 2009, cited in Livioara, 2010).

Jørgensen (2012) summarises some observations that arise from a comparison of Weber and Kafka perspective:

- The ideal bureaucratic system is excellent in every respect, all agencies are inherently controlled, which in Grigoriou’s (2013) terms, rationalise, implement and professionalise administrative processes, and so errors cannot occur.
- As everything is expected to be under control, infallibility becomes an organisational ideology, and external control is unnecessary.
• If errors occur, the system runs away because in reality it is not fitted to cope with errors, nor has the urge to react to them, as it must then recognise that it was an error and there is not capacity to expect or respond to errors.
• Endless hierarchy means that one can never know if an error really was an error.
• A consequence is that small errors can accumulate, their accumulation having the potential to become massive.
• A perfect and exact (and perhaps also inflexible) system is extremely sensitive and breaks down after a period of strain.

From this it must be recognised that there is a distinction here between “control agencies” which simply rationalise, implement and professionalise administrative processes, and “control processes” which create adjustments as required by a system. When discussing control here, reference is being made to the latter unless indicated differently.

So a bureaucracy is not a viable and adaptable organisation, as it can move from rationality to enigma, disconnecting itself from society and embracing systemic power that refers only to itself. If viewed as an autonomous system, its rigid structure means that it is therefore disconnected from attributes that enable it to develop autonomously in an evolving partnership with its symbiotic political system. In many ways therefore, it reduces to an instrumental system that is able only to implement its strategic attributes operatively, but not to introduce new strategic attributes.

**Connecting the political and bureaucracy systems**

One of the features of all autonomous organisations, whether they are nation States or Corporate enterprises, is that they are political. Most corporate and State organisations also have bureaucracies that operate through hierarchical structures. The political dimension of an autonomous organisation develops through a political culture that is responsible for political awareness. Political culture is “learned behaviour”, and this implies processes of socialisation that involves the creation of values, attitudes and beliefs that influence a political positioning and the formation of political ideology and ethics (Rosenbaum, 1972, p. 13). Political culture defines the normative context that allows politics to arise and includes the ideals, beliefs, values, symbols, stories and public rituals that bind people together allowing them to come to common action (Hunter, 2002). Political culture is ultimately responsible for political processes that distributes power and acts to constrain and facilitate certain types of politically acceptable behaviour. This facilitation is enabled by political structure and associated political behaviour that coincides with the ideals that arise from the culture which reinforces normative boundaries.

Political culture also enables the creation of boundaries for political legitimacy and the possibilities for political behaviour, and it provides options for modes of operations deriving from the political structures that constrain social processes. These structures normally maintain political executives, supported by a political bureaucracy. Thus, bureaucracy mediates between the stakeholders who may be subject to the political processes and the political executive which is responsible for them.

For Grigoriou (2013), bureaucracy becomes progressively both omnipresent and omnipotent through policy formulation, implementation and servicing – these arising from acts of governance. This strengthens the bureaucracy and widens its sphere of operation. Grigoriou considers that as a result bureaucracy may be seen as part of governance through the operations of its functionaries, and characterised by tendency towards sometimes inappropriate intervention that goes beyond its brief. The nature of this part is not
discussed, but drawing on Jørgensen (2012), it is perhaps most likely seen as an intimate interactive partnership.

So, what might this partnership look like, and how might it relate to both Weber’s and Kafka’s models? To explore this, distinction will be made between slave and autonomy propositions. In the slave proposition of a bureaucracy, a political executive is responsible for governance for which its Weber blueprint administrative bureaucracy slaves away to objectively service its policy development and implementation needs. In the autonomy proposition, the executive is a political decision-making system from which policies arise in interaction with its administrative bureaucracy system. These interact, and after the bureaucracy helps the political system in its policy formulation and development, it becomes responsible for policy implementation and servicing. This autonomy proposition would likely be implicitly supported by Jørgensen, for which elementary support comes by looking the nature of change in each system. In the political system, substantive political executive substitution occurs from time to time through processes of election (especially under political instability), while in the bureaucratic system, change occurs incrementally through the movement in and out of the organisation of individual functionaries. This construct makes the interaction between a political system and its bureaucracy look harmless. However, there are important political issues to be considered. Where democratic control is weak, perhaps because a government has a strong majority, then it may reshuffle the whole bureaucracy. Here, new ministries may be constructed, and old ones depleted of personnel, power and expertise, becoming neutered with respect to possible consultation, advice or action in relation to significant social issues.

There is also an issue about whether the functionaries of a bureaucracy take on a subservient advisory role for the political executive, or whether they take responsibility for the development and implementation of policy decisions. Grigoriou notes that a bureaucracy is often involved in every stage of policy-making process, allowing functionaries to operate beyond their brief and the relevant ethical framework that guides proper advisory conduct.

Grigoriou (2013) also indirectly supports the autonomy proposition when he says that the nature and differentiated functions in governance (referring to the State system) demand well-trained functionaries to administer and manage the complexity and differentiation that characterise executive policy requirements. These functionaries have the power of permanence and non-elective status and are able to apply and even initiate measures of control over national administration and economy. Thus, while bureaucracy may be crucial for executive performance, it is also “largely impervious to control by the people or their elected representatives” (Grigoriou, 2013, p.3). An example of this is provided by Hood (1995) who describes the attempt with uncertain outcome to make dramatic changes to the UK Civil Service in the 1980s through the replacement of senior functionaries by Prime Minister Thatcher.

So political systems may become overshadowed by their bureaucracies, and bureaucracies are subject to attempts for change by the political system. There is a specific term that is used to explain when a political system becomes overshadowed by its bureaucracy. Habermas (1987) has discussed this process at length through the introduction of the lifeworld: the processes of thematic communication in a network of participants that deliver meaning to participants thus creating a potential for understanding. When a bureaucracy overshadows its political system, it is said to colonise its lifeworld. When this occurs, the political system is prevented from internal considerations of how to apply steering media (power or money) to given situations. In other words, the communicative potentials for understanding contained within the lifeworld are eroded, and the systemic imperatives of bureaucratic interventions colonise and dominate lifeworld processes.
consequence is that the association between the lifeworld and the political system’s decision processes become “uncoupled”, and its internal semantic coherence is impaired. Here then, values and goals can become compromised by those of the bureaucracy. When the political system’s normal pattern of semantic communication that defines its lifeworld is disturbed sufficiently by such colonisation to endanger its reproduction of knowledge, the situation is pathological. Having explained colonisation and related it to an effective control of the political system by the bureaucracy, it is also possible for colonisation to work the other way, with effective control by the political system on the bureaucracy system. As the intended purpose of a bureaucracy is to service the needs of its political system, colonisation of the bureaucracy would be considered unusual, except where the political system wishes to release implicit controls of the application of its power. Thus, it is more likely to occur when the political system having power has unchallenged dominance (as in the case of large majorities in a democracy), or in despotic situations.

An illustration of colonisation is possible. Using the definition of a bureaucracy provided at the beginning of this paper, the university sector may be seen as a bureaucracy. Here, universities provide services designed to implement government policy to implement social needs for higher education. Accepting that a university is therefore a bureaucracy, then according to Kay (2012) the Thatcher government, with its extremely high majority, colonised it through its policy of higher education reformation in the 1980s, ultimately creating a shift in culture by abandoning cognitive values and embracing economic values in the university sector, a shift consistent the political ideology of the governing body.

Illustration of political space colonisation by bureaucracy is stylised in the BBC television series (BBC, 2014) “Yes Minister”. Here, the Right Honourable James Hacker MP who is Minister for Administrative Affairs attempts to make sense of bureaucratic officialdom and administration. As he does this he pursues his own self-serving agenda while attempting to keep his head above any negative political situations. His chief administrative advisor is the civil servant Sir Humphrey Appleby. The Minister’s policies, whether cutting costs or trying to streamline red tape, are sabotaged by the Machiavellian capabilities of his functionary advisor. A snob and elitist with tunnel vision, Sir Humphrey is the avatar of the British State unable to see anything that lies beyond service to the British Civil Service. This parody of the British Civil Service underlines the argument by Jørgensen (2012) that the natural bent of a functionary is to be subjective, particular, emotional, biased or prejudiced, partial or particular. Like others, he therefore agrees that the power of the functionary needs to be regulated.

The possibility of excesses performed by bureaucracy functionaries in their dealing with stakeholders is often responded to through exceptional political controls. Grogoriou notes that one of these is the political role of ombudsman, whose independent brief is to investigate complaints of maladministration that impact on civil rights concerning actions resulting from a political bureaucracy. In other cases, he notes, collective decision-making is encouraged within organisational structures that are intended to reduce the impact of hierarchies and distribute the power to make decisions.

Another consideration relates to social complexity due to economic and political modernisation, resulting in new forms of life style that for Grigoriou (2013) is a consequence of capitalism. As a response one is told, the concept of the welfare State has arisen. This takes responsibility for the protection and welfare of the citizen in the context of a dynamic economy. To service this, the State has become a standing authority in which alienating power increases. It is operated on behalf of society by the State through certain institutions, structures and agencies, bureaucracy being the most significant.
Merton (1940) explains that bureaucracy functionaries have a collective sense of destiny and share related professional interests. Merton did not recognize these as embryonic cultural elements that could facilitate the emergence of an autonomous culture, even in Weber's ideal of a bureaucracy. These attributes reflect on their goals and ideology, which determine their strategic orientations and regulate their behaviors. Merton also notes that these embryonic cultural elements of the functionary often lead to the accumulation of entrenched interests that works against their stakeholder clientele and elected officials. In one such scenario, if bureaucrats do not consider their status to be adequately recognized by an incoming elected official, detailed information will often be withheld leading to errors for which the official becomes responsible. In another scenario, if the official seeks to become dominant, thereby violating sentiments of bureaucratic functionary self-integrity, they may be intentionally overwhelmed by documentation for requiring decision or action.

So, a bureaucracy involves functionaries who respond to newly elected political personnel, doing so according to their own ideological and goal orientations. According to Mazlish (1990), ideologies become institutionalized when they become embedded in bureaucracies that control meaning and develop systems of administration. This is different from the more frequent notion that a bureaucracy will simply reflect a given political ideology. In other words, there is an interaction between a bureaucracy and the operative consequences of a political ideology that affects the development of both the bureaucracy and the ideology. When a bureaucracy upholds ideology such that it becomes prescribed as a doctrine, Mazlish notes, it may become linked with (conscious or non-conscious) cultural totalitarianism, and consequently also with political totalitarianism.

While bureaucracy controls meaning and develops systems of administration, there is an ultimate interaction between a bureaucracy and a political ideology that affects the development of both. One explanation for the interaction between them is that bureaucracies operate through the subjectivity of leaders, and both the leaders and the led define themselves and their relationship through their association within their shared culture (Fromm, 1961). During this process, a selection is made from their shared culture that is codified by ideology. It is made real and alive to the led through the leader’s image, but is also subject to the manifesting developmental potential of those being led. It is the bureaucracy that helps decide on ethical issues: that is, what is right and wrong thinking in a social community. While ethical issues provide for moral judgements, ultimately such judgements can be used to identify who is faithful to a political bureaucracy and who is not. As part of a political process, it determines who of the ideologically unfaithful is a heretic. Thus, for Mazlish (1990), the manipulation of ideologies becomes one of the most important means for the control of people, through the control of their thoughts.

This discussion that distinguishes between the abstract blueprint and the pragmatic model of bureaucracy highlights something quite significant. That bureaucracy has at least two representations. One is that it is a rule-based system that serves the interests and needs of (usually) an elected executive. The other is that it is an autonomous system that services and interacts with the political system.

In what follows here, both of these models will be explored, identifying some of their properties on the way. To do this, Cultural Agency Theory will be adopted to represent the modes, primarily because of its flexibility and power in representing both formulations.

**Cultural agency theory**

Cultural agency sits on the concept of agency, which is some entity that has the capacity, condition or state of acting or of exerting power. Agency theory is concerned with the relationship between two or more parties who may act as agencies to each other, and is
concerned with the determination of the general structure that they have to enable them to be agencies, and the interactive relationships between them. By general structure is meant the meta-structure, where the term meta can be used to mean something that is characteristically self-referential. Meta-structure can be seen as offering an overarching framework which supplies rules regarding the relationship between meanings within a defined frame of reference. It may be seen in terms of complex processes through which the emergence of collective interactive phenomena develops, resulting in individual or collective behaviours acquiring emergent properties.

Agency theory has a widely applied theoretical and empirical framework that can be used with different disciplines and approaches (Kivisto, 2007). In organisation theory, its purpose was initially to investigate more general questions of incomplete information and risk sharing and is concerned with analysing and resolving problems that can occur in agency relationships. The theory assumes that a principle delegates authority to agents, but have issues because strategic attributes like goals and information about capacities and activities vary. The approach focuses on the ways principals try to address the control problem by selecting certain types of agents and certain forms of monitoring their actions and by using economic incentives. Eisenhardt (1989) has noted its significance for the development of coherent modelling. A much broader view that this is offered by Bandura (1986), who is interested in the field of human psychology and self-processes that connect with environment and other agencies in interaction. He notes that agency as a self-system has been conceptualised in at least three different ways, namely, autonomous agency, mechanical agency and emergent interactive agency:

1. **Autonomous agency** – Misunderstanding that there is a distinction between autonomous and isolated agency, Bandura dismisses this without much further regard saying that no real agency is autonomous (meaning isolated) from interaction with others. The term autonomous is usually used within the context of interactive environments, where an autonomous system is self-directed while also being influenced by its environment. It may additionally have its own immanent dynamics that impact on the way it interacts.

2. **Mechanical agency** – Seen as an internal instrumentality through which external influences operate mechanistically on action, this approach eliminates properties of motivation, self-reflection, self-reaction, creativity and self-direction, topics that likewise are not present in soft inquiry approaches. In this view, internal events are a reflection of the impact of external environments from which causal attributes are ignored, and the self-system is merely a repository and conduit for environmental forces, and as such self-influences do not exist. This perspective appears to be more reflective of Eisenhardt’s understanding of agency and quite reflective of Weber’s view of a bureaucracy were it to be classed as an agency.

3. **Emergent interactive agency** – Bandura’s approach is rather to embrace emergent interactive agency applying perspectives of social cognition. Here, an agency makes causal contributions to its own motivations and actions using “reciprocal causation”. This latter adopts attributes of self-regulation and control, and action, cognition, affect and other personal, environmental and interactive factors are involved. For Yoon (2010), this approach also refers to the capacity of the agent to exercise control over the nature and quality of its life, and in doing so operating with four core features, namely, intentionality, forethought, self-reactiveness and self-reflectiveness. Agencies are also proactive, self-organizing and self-regulating. They are participative in creating their own behaviour and contribute to their life...
Autonomous agency theory, when formulated to operate through culture, is also referred to as Cultural Agency Theory. It sets Emergent Interactive Agency Theory into a complex cybernetic “living systems” framework (Yolles and Fink, 2015) that redefines Bandura’s conception of the autonomous system approach. The concept of an autonomous living system as adopted here arises with the work of Schwarz (1994). This sits on the foundational work by Miller (1978) whose conceptualisations reduce the complexity of the structure and organisation of living systems. Miller provides a common framework for analysing the nature, condition, structure and process of systems at various levels of complexity. This ability to compress complexity was important to living systems theory. It also sits on the work of Maturana and Varela (1980) who were interested in the biological basis of living and created a generic modelling approach that has the capacity to anticipate future potentials for behaviour.

One of the central features of agency theory is its ability to maintain viability through a capacity to adapt and transform. The concept of viability was central to Stafford Beer’s theory of management cybernetics. While agency is essentially a third-order cybernetic theory, unlike Beer’s (1979) second-order theory, the two have a relationship. For instance, Beer’s (1959) proposition on viability, which says that every viable system contains and is contained in a viable system, is adopted and transformed in agency theory to become every viable living system contains and is contained in a viable living system. This principle will be adopted later.

Yolles (2006) developed the basis for Cultural Agency Theory. Such an agency is a living system represented through a substructure. This substructure is constructed as a generic system. This houses superstructure, composed of testable propositions that conceptually enrich substructure, and often migrated from other commensurable theories. The substructure has various dynamic properties that include autonomy and a potential for viability and hence adaptability. Agency also implicitly embraces inherent dynamic superstructural attributes that arise from socio-cognitive theory. These include collective identity, cognition, emotion, personality; purpose and intention and self-reference, self-awareness, self-reflection, self-regulation and self-organisation. Cultural agencies also interact in an environment with others attributes, including agencies. The basic model of the generic system is shown in Figure 1.

A, B and C all contain particular attributes of an autonomous system that are closely linked and that together form a living system. Whatever is contained in the ontological domains is superstructure. There is a coupling between the two distinct but related ontological domains A and B, both of which form a connected couple through a network of processes called self-production, which allows the living system to manifest elements from B to A, with feedback back to B indicating the consequences of this manifestation. This is controlled by self-creation which occurs through the manifestation of elements of C to the couple of A and B. These two networks of processes have also been identified respectively as figurative and operative intelligence, terms that arise with Piaget’s (1950) work in child development. The natures of A, B and C are determined by the contextual environment that the systems is exposed to, and their meanings change with that context. One of the features of Figure 1 is that it is recursive (Yolles, 2006) as every living system may contain within it another living system.

So what are these three ontological domains, and why do they constitute a viable living system in the assembly shown in Figure 1? Schwarz (2002) was interested in exploring viability within the context of autopoiesis (self-production). He argued that for autopoiesis to
be a core element of a living system, it requires three ontological attributes. Relating these attributes to Figure 1, the holistic domain (C) constitutes “the whole”, the potential domain (B) is one of relations and the physical plane (A) of objects. Interestingly, Yolles et al. (2011) in their development of this model as Cultural Agency Theory discovered that domain C is an attractor for states that appear in domains B and A. It may be noted here that while domains have ontological properties, they do not possess functionality. This is actually an issue if one is interested in changing contexts. It can be resolved by replacing the ontologies with functionally related substructural systems. The outcome of this is not substantive except in that it increases flexibility, permits the substructural systems to take on both the ontological properties associated with the domains in which they reside and context-sensitive functionality. A consequence of this is that while the domains are not susceptible to changes in categories of being under different contexts, the substructural systems are, and the specification of their natures thus changes with context.

The model in Figure 1 is not just a static one, but there is insufficient space to explore its dynamics of life and death here. The nature of self-production that arises conceptually from Maturana and Varela (1980) as a network of manifesting processes is central to the autonomous agency, and creates an instrumental system where elements of B, like strategic goals, can be manifested to A, the system’s operative system. Self-creation is also a network of processes that facilitates learning in the autonomous system, and controls the A-B couple. The relationship between each domain and the networks of processes that connect them is explained in some detail by Yolles and Fink (2015).

The slave proposition for the bureaucracy
Practically, operative intelligence develops through ministerial leadership in interaction with its bureaucratic aids who take on the mantel of embracing ministerial decisions for intended action. This action involves interpreting political decisions and manifesting them (with all of their complex dimensions) to various departments of the bureaucracy for (hopefully efficacious) implementation. While the bureaucracy may interpret decisions according to its traditional culture, those decisions are practically manifested through a rule-based process. Most governments operate under degrees of inefficacy it would seem, as most governments implement policies that are not coherent (especially when a policy relates to other policies that come from other ministries). This is because in different fields of activity, different interests are perused. As a result, governmental conflicts of interest arise.

Figure 1.
Basic model of the living system developed from Schwarz (1994) by Yolles (2006)
Figure 2 is a cultural agency model for a political system, deriving from Figure 1, where the context is the socio-political environment. Political decisions made in its strategic domain are manifested through a network of political operative processes which constitutes its operative political intelligence, thereby delivering it into its political structure constituted in part by the bureaucracy that facilitates its capacity of policy implementation. Similarly, political knowledge is delivered to the strategic-operative couple through figurative political intelligence. The system as a whole is sensitive to the environment and survives by virtue of its capacity to adapt, learn and self-organise.

The three ontological dimensions of the political agency are, namely, culture, figurative strategy and operative structure, with its related behaviour. Behaviour is facilitated and constrained, but not caused by structure, and they are otherwise independent. Political figurative strategy is where decision-making occurs and maintains political attitudes, and cognitive schemas like goals, political ideology and ethics and political self-schemas including the possibility of political adaptation. Figurative strategy exists in an interactive instrumental feedback and adjustment couple with political operative structure. In this latter, political decisions are delivered to the operative system through operative intelligence that is a component of the bureaucracy that is essential to the political agency. Both are, however, conditioned by culture. When talking of culture, a general existential condition will be meant that maintains a belief system and supports patterns of knowledge and understanding. The importance of political culture is that it has embedded political knowledge that influences ideology and ethics. It can also facilitate empowerment that “formally” if not practically.
liberates the individual or group potential to perform certain types of agency operative behaviour. Thus, in some corporate environments, employees are empowered to make certain types of decision that directly result in behaviour, and they do this without having requesting permission from more senior roles. However, when “push comes to shove”, the degree of such empowerment is often highly limited by the political bureaucracy.

Another problem often comes with structures. Many social collectives maintain restrictive hierarchical structures. They are the result of a political culture that is responsible for political awareness. For Rosenbaum (1972, p. 13), political culture is “learned behaviour”, implying processes of socialisation involving the creation of values, attitudes and beliefs that influence a political positioning and the formation of political ideology and ethics. According to Hunter (2002), political culture defines the normative context within which politics occur and through which a political agency operates. This context includes the ideals, beliefs, values, symbols, stories and public rituals that bind people together and direct them in common action. Political culture is ultimately responsible for political processes that establish power distributions, which act to constrain and facilitate certain types of politically acceptable behaviour. This occurs through political structure with relatable action that is a reflection of that culture’s ideals and, in turn, reinforces that culture’s normative boundaries.

Political culture also provides the boundaries of political legitimacy and the horizons of political possibility and defines modes of operations that reside in the political structures that are defined and that constrain social processes. These structures normally maintain political executives (in a pluralistic political environment there are more than one executive, which can result in competition and conflict) supported by a political bureaucracy. This mediates between members of the social collective subjected to the political processes, and the executive(s). However, bureaucracy also maintains a political culture with resulting power structures and modes of operation that may be, but are unlikely to be, a complete reflection of the political culture of the agency in which they reside. This is because a bureaucracy may be bedded in a more traditional political culture the remnants of which are maintained by the traditions that the bureaucracy maintains. There may, therefore, be an interaction between a political agency and its traditional bureaucracy from which operative instabilities may arise.

Bureaucracy can also be represented as living system agency which has the capacity to survive under change through adaptation. It operates through a system of rules that connect with to social data to develop and implement political decisions in an appropriate contextually sensitive way (Figure 3). This bureaucracy living system can be considered to operate through three meta-systems in a political context defined by patterns of operative rules. The cognitive bureaucracy system maintains patterns of categories that can be applied to policy attributes in the real-world environment. These patterns are matched to data that are migrated to the cognitive bureaucracy system. The figurative bureaucracy system develops a selected set of rules that are appropriate to distinguish sets of processed data that is contextually related to the environment. The operative bureaucracy system develops operative structures through which decisions are implemented, and to which behaviours are anchored. These structures both facilitate and constrain behaviours thereby limiting their independence.

The operative and figurative bureaucracy systems form an interactive couple linked by operative bureaucracy intelligence. Figurative bureaucracy intelligence is a network of processes that matches patterns of data with patterns of category according to patterns of rules, and delivers the outcome to the strategic bureaucratic system as goals strategies. It also offers a frame of reference for the operative bureaucratic system. Figurative
bureaucracy feedback has a pathological filter that is triggered by functionaries in the bureaucratic system, limiting its capacity to create imperatives for change about rules or categories. These filters may be formal: being imposed through governance – perhaps to “preserve some bureaucracy ideal” or having sanction by the bureaucracy senior functionaries. It may also be informal: arising either with consensus through some form of cognitive conditioning or through idiosyncratic individuals or groups. Changes in role positions may or may change the filters, as illustrated by personnel shifts in Nigeria (Rasul and Rogger, 2013). Operative bureaucracy intelligence is a network of processes that applies the appropriate rules of the bureaucracy to processed data that arise from the cognitive bureaucracy system to manifest operative structures. Feedback from the operative bureaucracy system generates imperatives for figurative bureaucracy adjustment or maintenance. However, it has a pathological filter that can limit the evolution of strategic attributes, and this includes potential action relating to a selection of categories. When the filter operates, the figurative-operative couple is instrumental as under the operation of the pathological filter, goals are unable to change.

The nature of these intelligences is that while they are networks of processes, they function with each other within a lifeworld (Habermas, 1987) through narratives. These intelligences will operate with some degree of efficacy (Bandura, 1977, 1986; Wood and Bandura, 1989). When they are inefficacious, it may be because the effectiveness of each intelligence process in the network is inadequate, or the narratives that are being adopted are idiosyncratic, thereby contributing overall to an intelligence that is populated by antenarratives (a collection of story fragments), that together generate an incoherent story. Recognition of this has resulted in attempts to create “joined-up” governance (O’Flynn et al., 2011; Bogdanor, 2005) intended to move from chaotic antenarrative to more coherent narrative.

Thus, bureaucracy agency is an integral component of the figurative structure of the political agency, as shown in Figure 4, though a readable if more complex representation is offered in Figure 5. Here, it is shown how political figurative intelligence manifests decisions and how political decision-making structures arise through bureaucracy.

There are two potential pathological feedback filters in the bureaucracy model, and when they occur, they are sanctioned by their culture and activated by functionaries, while
inherently supported by the bureaucratic hierarchical structure. These filters create the potential to isolate the operative system from generating feedback to the pattern of rules in its cognitive system, and the development of goals, ideology and self-schemas in the strategic system. This has the potential to inhibit controlled development and learning.

The autonomous proposition for the bureaucracy
Instead of seeing the bureaucracy as dedicated slave to a rule system as shown in Figures 3-5, it may be rather seen as an autonomous system in its own right in interaction with its political system. As such, it has its own cultural system with a proprietary culture that influences its ideology and goal perspectives, and determines how it receives policy formation and implementation requests demands an existing executive undertaking governance. If one therefore considers a political regime in power as a cultural agency that interacts with a bureaucracy that is itself a cultural agency, the outcome is as shown in Figure 6.

Here, it is shown as an autonomous system, where bureaucracy is pathological in that its cultural system is constrained, disallowing the creation of new knowledge or innovation, potential adjustment of its strategic ideologies or goals or self-schemas that determine its mode of being. It does, however, behave as an instrumental system that for its strategic system will operate according the perceived needs of its partner political system. However, there is no feedback to this system, so that strategic attributes are unable to be adjusted. This characterises a great deal of systemic rigidity.
Figure 6 has arisen dynamically from the Weberian blueprint in Figures 4 and 5 and promises the possibility as a worst-case scenario of a Kafaian bureaucracy. This is because the feedback mechanisms are pathological, and so the bureaucracy is not a learning system or an instrumental system.

The bureaucracy system does change however. There is a theory of organisational change (Greiner, 1972, 1998), but this is concerned with the life cycle of autonomous systems. However, the Weberian blueprint is not a full autonomous system, having no feedback and hence no capacity for self-organisation.

In the blueprint bureaucracy, a pathological filter or even a block on the figurative intelligence feedback limits or inhibits the development of new patterns of rules. Also, a pathological filter or block on operative intelligence feedback limits or inhibits the development of strategic options, including the creation of new categories. Any changes that do occur here
must result from the interaction between the operative attribute of the political system, this latter initiating the change. This is also the case with the pattern of rules used by the bureaucracy. Thus, the bureaucracy is neither a learning system nor an instrumental system. In effect changes in the Weberian blueprint ideal occur as a dynamic that can find itself on a trajectory towards a Kafkian pragmatic bureaucracy. The dynamic process is not problematic to identify. Starting as an intended durable rule-based living system, the blueprint begins to develop away from the political system towards independence by establishing its own culture alongside its pattern of rules, which now becomes established as cultural knowledge. It also converts its strategic attributes into a “personality” (Yolles and Fink, 2014) from which patterns of behaviour are manifested. However, as both the culture and “personality” have been constructed with limited or without feedback and reflection, both of these are prone to pathologies which are never self-assessed or evaluated. This allows a Kafkian medusa to arise. Consistent with Grigoriou (2013) and others as discussed earlier, control needs to be imposed from the political system. As initially requires evaluation and assessment from the political system, followed by action for change. However, this easier said than done as creating a cultural change is one of the more difficult things to do in a mature organisation, especially if it derives from an external agency imposing its will on the bureaucratic system.

The political and bureaucratic systems interact only operatively as strategic and cultural systems can only be seen by other systems as manifestations in an operative environment.
So for instance, the bureaucracy system can only see cultural aspects of the political system through its operative legacy, like its specified policies or artefacts. Policy decisions are delivered to the bureaucracy, which will in turn offer practical guidance in relation to its formation and assist its processes of implementation. However, during this process, there is the likelihood that the practical outcome of the policy will have a meaning that differs from that of the intended policy. This may in effect result in effective political system strategy corruption, including in some cases the perturbation of intentions by corrupt ministers.

Discussion
This paper initially cited smart governance as its interest. This context has directed the reader towards the limitations of smartness due, not to innateness of a political administration, but rather to the implementation of good social improvement policy through a possible pathological bureaucracy that manifests inadequate policy.

It has been argued that the trust and stability of a political institution is partly dependent on the efficacy it has in developing and implementing policy proposals. However, the means by which policy design and implementation from context-sensitive goals involve the use of a bureaucracy, making an understanding of the relationship between the administration and its bureaucracy paramount. Making efficacy comparisons of political administrations across political systems is therefore likely to lead to unsustainable results if comparisons of their bureaucracies are not part of the evaluation process. The explanation for this is relatively straightforward.

We have defined a bureaucracy as a social subsystem of administrative structure that functions within a given frame of reference, operates through a set of regulations control of activities through processes of rationalisation, operative facilitation under profession conditions, these activities to deliver services on behalf of some governing policy directive. The consequence of this definition is that any service organisation that operates with a given frame of reference under some form of administrative governance can be identified as a bureaucracy. The administrative system through which governance is delivered has its needs serviced by a bureaucracy. This is a broader definition than is normally adopted. It permits a political system to itself be seen as a higher-level bureaucracy, possibly also serving the needs of a higher-order administrative system. In other words, whether a bureaucracy is a political system depends on the context defined, the frame of reference and the focus that determines what administrative system and subsystem you are looking at. Thus, the connection between a political system and the bureaucracy that serves it is a recursive one.

So, for instance, a Corporation that runs a chain of residential homes for the elderly is an administrative system with a frame of reference of care, and it governs the activities of each home which then may be seen as bureaucracy. At a lower focus, each residence for the elderly may be seen as an administrative system with an executive that governs the activities of the home, serviced by a structured bureaucracy that is responsible for delivering various dimensions of service. This structure advises and guides the executive about the needs of residents, and contributes information enabling the executive to make decisions, deliver policy and guide behaviours that constitute the operative end of the organisation.

The Weber blueprint for a bureaucracy provides an efficient model to assist the policy formation and implementation of political systems, though this efficiency is significantly reduced to the limit of a Kafkian model when it involves people. Seen as a living system, the bureaucracy is composed of a cognitive pattern of rules from which strategic approaches arise that through processes of categorisation enable goals to be formulated. These then
become actionable when they are manifested operatively to service the perceived political needs (by the political system) of citizens. However, these perceived needs may be different for the political and the bureaucracy systems, and the operative outcome may be the result of an implementation that does not conform to political system expectations.

This is because a bureaucracy is seen as an integral part of the operative political system, having a function to control political power. While the bureaucracy blueprint is supposed to be efficient, it is not intended to be effective. For this to happen, monitoring checks are required, but these are not part of the institutional process that defines the blueprint. This is not surprising as the blueprint is intended to be part of the operative attributes of the political system which centres on rules and rule systems and is devoid of the meanings that might be associated with effectiveness.

Modelling the Weber and Kafka models through agency theory has shown that the Weber-related agency model of bureaucracy is an unreachable bound for the Kafka-related agency model. Bureaucracies should therefore be taken as autonomous organisations with pathologies. Supposing that a political administration seeks policies that improve society, then how a bureaucracy’s pathologies are able to misapply them is a point of inquiry.

If it is accepted that a dynamic from Weberian bound to Kafkian in bureaucracy can develop, perhaps the simplest integral explanation is that there is an evolutionary process going on. Here, the bureaucracy emerges as an autonomous system in its own right. This occurs as its embryonic cultural system constituted as a pattern of rules and collective sense of destiny and professional interests become transformed into a set of cultural knowledge, values and beliefs that guide its development, strategic aspirations and operative conduct. The bureaucracy now has the potential to develop as any autonomous living system will, with adaptation, self-regulation, self-reflection, self-organisations, etc. However, this potential is curtailed because of the strict hierarchic nature it maintains and limitations imposed through its culture and by its functionaries. Any possible adaptation it passes through is filtered by a usually traditional and conservative culture, a condition in part surely due to political appointment selection procedures. Even if new appointees are not traditional and conservative, they are likely to so become as they fit in with the cultural imperatives that enable them to do their job. The functionaries are responsible for the imposition of feedback filters on the bureaucracy system in respect of both its figurative and operative intelligences, thus:

1. limiting its capacity to be an instrumental feedback system therefore monitoring and controlling the way in which goals are implemented; and
2. learning through the development of its patterns of rules.

These filters can act as bureaucracy pathologies, inhibiting reflection or error correction processes. It is through such a mechanism that Kafkian socially toxic bureaucracies can develop.

Due to their autonomy, the political and bureaucracy systems can only interact through their operative systems as its figurative and cultural system becomes closed to others in the outside world. As such, it may not be that the bureaucracy system just services the requirements of the political system but may instead introduce its own political attributes on any policy specification or implementation.

As a consequence, it must be realised that traditional approaches to governance, based on normative and procedural compliance to political leaders, are inadequate. Policymakers (either in a State or Corporate environment) may formulate detailed and strict sets of rules as, for example, has happened in the Banking Sector with the European rules with Basel III (Hannoun, 2010; Blundell-Wignall and Atkinson, 2010). However, they are interpreted in the bureaucratic system, with its own worldview and norms, and meanings change as they
become migrated into the bureaucracy system culture within its own set of meanings and contexts. As a result, few interventions to reform bureaucracy systems are likely to have any significant long-term impact, and reform failure is inevitable.

The alternative to this is to eliminate the fiction that a bureaucracy is an ideal system that just requires occasional adjustment, and recognise what it is exactly, a pathological autonomous system with its own culture that if in need of change, requires a change management approach like Whole Systems Change (Macfarlane et al., 2011; Iles and Yolles, 2003). Other more piecemeal approaches to change will not work as expected.

To finalise this study, it is useful to return to questions asked in the introduction. The first is, do the perspectives of the bureaucratic functionary cloud its brief? The clear answer to this is yes. However, when the bureaucracy has become an autonomous living system, the perspective adopted is a “professional” one that is culture centred, rather than an individual one. The second question is, if there are commonalities among the personalities that create bureaucratic norms, does a bureaucracy therefore maintain its own culture that is distinct from that of a given political regime? Clearly the response to this is yes as the bureaucracy has moved from an operative phenomenon to an autonomous system with its own culture. The third question put is, how does this impact of the “efficiency” or the “effectiveness” of the implementation of political policy decisions delivered by governance? It is not only efficiency that is of significance, but efficacy. Bureaucracies can be efficient even where they have developed as an autonomous system. Efficacy is another matter, as it is ultimately connected with meaning. In the unlikely but best case scenario, let us suppose that meanings are identical in the political and bureaucratic systems. The problem is that effectiveness is concerned with the ability of one entity responsible for processing one aspect of a policy, to be efficient in its “intelligent” processes. In contrast, efficacy is concerned with the whole collection of processes, and might be evaluated as some sort of average over the whole set of efficiencies. Efficacy is therefore more problematic to evaluate. Even if a single process is effective, there may be divergences between different entities responsible for different processes. Thus, for instance, the manifestation of a goal may have a number of sub-goal dimensions. However, in pragmatic systems where subcultures reign, there are often misunderstandings about the nature of a sub-goal, resulting in goal divergences. Where resources are scarce, there are always goal conflicts, even within a single government agency. Bureaucracies may be able to assist through the evaluation of advantage in respect of goal conflicts. They do this by becoming involved in the processes through which goals become manifested operatively while maintain meaningful communications among goal stakeholders. This is frequently missing from the communicative lifeworld of the bureaucracy. As a result, each entity may maintain a different goal narrative from others involved. The outcome is a chaotic antenarrative that if heard creates nothing but confusion. In State politics, the term “joined-up” government become popular in various countries, with political ambitions to create a more efficacious system that itself creates a great wish list if little else.

Limitations of the paper
This paper has found that all bureaucracies can be modelled as autonomous agencies with potentially determinable pathologies. While this paper has distinguished between agency models for Weber’s unattainable boundary bureaucracy (making this agency model irrelevant), and the more pragmatic Kafka model, other that brief illustration, no attempt has been made to demonstrate that real situation case bureaucracies can be expressed in terms the bureaucracy agencies with identifiable pathologies. This would be a very useful extension to the paper as it would show how the pathologies provide a potential for social harm able to destroy the social good of right intended policies.
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Further reading


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Governance for intelligent organizations: a cybernetic contribution
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Abstract
Purpose – This paper aims to revisit the viable system model (VSM) discussing it from both the theoretical and the empirical standpoints, and ascertaining its relevance for organizational governance.

Design/methodology/approach – A combination of theoretical and empirical components is used: introduction to theory and critique on the one hand; case studies and a large sample empirical study on the other.

Findings – The VSM has proved to be a powerful means of governance for organizations in turbulent times. It conveys a durable, reliable knowledge. This has been corroborated in both case studies and a large-scale empirical study.

Practical implications – Application of the model under study can activate a huge potential for the improvement of organizations.

Originality/value – This contribution tests the VSM in an unseen fashion – qualitatively and quantitatively. The results suggest that a high confidence in the model is justified. It conveys to managers and leaders an unconventional, superior approach to both diagnosis and design of their organizations.

Keywords Governance, Sustainability, Cybernetics, Viable system model, Organization design, Organizational diagnosis

1. Introduction
We all know that the environment of organizations poses formidable challenges. It is dynamic and it confronts companies with huge uncertainties, with ambiguity and dynamic complexity. Only intelligent organizations can cope with that: the ones that adapt and learn to be viable.

The purpose of this paper is to introduce a powerful model that has much to offer for an organizational governance directed at the viability of organizations: the viable system model (VSM). The model emanates from the tradition of cybernetics, the science of communication and control of complex dynamic systems (Wiener, 1948). Its goes back to Stafford Beer, the father of management cybernetics[1], and has been discussed in this journal before (Schuhmann, 2004; Sergeyev and Moscardini, 2006; Schwaninger, 2006a; Gmür et al., 2010; Pérez Ríos, 2010; Espinosa et al., 2011, Schwaninger, 2012). The present article revisits the VSM with the intention to combine the theoretical and empirical views on the model.

There exist other introductions, which usually present both an introduction to the theory and a demonstration of the application of the model (Beer, 1979; Espinosa and Walker, 2006; Espejo and Reyes, 2011). We aim to introduce the model in a way particularly useful to
readers who know the basics of the VSM, but miss an exposure to accounts of its application: while we only give the theory in a very succinct form, we present examples of applications of the model, and we deliver the results of recent studies by which it has been tested empirically in more extensive ways. Finally, we report on critiques of the VSM and the implications of our study.

2. Governance in perspective

From a cybernetic perspective, the concept of governance is, in principle, comprehensive: both terms cybernetics and governance derive from the Greek kybernetike, which stands for the art of steersmanship. In modern times, governor has been used for technological systems of regulation (“controllers”) (Maxwell, 1868) and for management systems (Beer, 1967). From a cybernetic view, there is little difference between governance on the one hand, and management or control, on the other.

The practice of governance in current definitions of the topic focuses on governance structures, processes and practices (Tricker, 2015). The seminal Cadbury Report (Committee on the Financial Aspects of Corporate Governance, 1992, p. 15) defines corporate governance as “the system by which companies are directed and controlled,” and specifies that the boards of directors are responsible for the governance of their companies. The shareholders are in charge of appointing the directors and auditors (Ibidem: 30).

The concept of organizational governance[2] is to a large extent about rules and regulations: it is considered a regulatory framework for the management of an organization[3]. In that sense, the role of governance is to ensure that the organization behaves and develops according to the expectations of the different stakeholder groups (Müller-Stewens and Brauer, 2009)[4]. Definitions of this kind abound; their common denominator is that they refer to the organization as a whole and to the level of normative management.

Accordingly, when addressing governance, we will mainly take the stance of normative management here – the ethos, norms, principles and values governing an organization, and strategy – the orientation of the organization in the long term, within its environment.

Hence, in relation with the topic of organizing, we will particularly deal with the principles of design, and in relation with the topic of control, with the principles of navigation.

In the turbulence we are facing, things are intransparent, everything changes fast and nothing is warranted. In these circumstances, orientation is crucial: instruments of navigation can help. We know them from shipping and aviation. In organizations, the principles of navigation have evolved over time.

Similar to the technical world, also in the organizational domain, the approaches to governance have had to change:

- The focus has shifted from profit maximization to the maintenance of viability.
- One-dimensional measures of performance are giving way to multidimensional concepts.
- The reductionist way of looking at things is being replaced by an integrative, holistic approach.
- If traditionally, management’s primary attention targeted shareholders, we are now recognizing the primacy of customers. The legitimacy of a company hinges – in the first place – on customers, not financiers.
- We are learning about the imperative of the long-term view and the need to balance both short and long term.
- Decision-makers’ interest will have to shift from symptoms to causal relationships.
Fired by the media the public interest is directed at events, for example, the demise of one bank during the banking crisis of 2008. But such an event by itself is meaningless. We have to look into the patterns of behavior in which the event is embedded, and at the underlying structures that produce this kind of pattern.

Is there an organizational design for better governance?

3. The viable system model
In our day, we have reliable orientation devices for a more effective governance. Here we will concentrate on the VSM, which has been used in many different contexts, although it cannot be considered to be known widely. Having applied the VSM for 30 years and worked together with Stafford Beer, the author has many examples to draw on.

3.1 Genesis and theoretical claim
The origin of the VSM is a vision: Stafford’s idea that management should learn from nature. The most adaptive higher organism in our cosmos is the human being. Hence, Beer studied if certain structural principles of the human organism could be transferred to organizations.

The result of that research was revolutionary. It came out that the basic structure of the human nervous system (Figure 1) can indeed be transferred to social systems of any kind. Beer discovered a homomorphic relationship between the two: any social system can be mapped unequivocally on the VSM. In addition, a social system and the nervous system can be mapped with one and the same model system – the VSM. This relationship is an isomorphism, i.e. it is bijective: the elements in each one of the two sets obey a one-to-one correspondence.

Figure 1. The human nervous system – a paragon for the structure of social organizations
This was not about a vague analogy but about a rigorous structural equivalence. The structure of a viable human organism, in a well-defined sense (Beer, 1981), equals the structure of a viable social organization. On the basis of that structural invariance, social systems can be diagnosed and designed (Figure 2).

Beer’s crucial theoretical orientor, when he developed the VSM, was Ross Asby’s Law of Requisite Variety: “Only variety can absorb variety.” (Ashby, 1956). This law provided the foundation for the architecture of the model: a set of homeostats, i.e. components whose mutual interactions, through a regulatory process, maintain a condition of equilibrium.

So much for the genesis of the VSM.

The theoretical claim of the model is that it specifies not only the necessary but also the sufficient preconditions for the viability of any social organism (Beer, 1979). This is a heavy claim, indeed: nothing alike is raised by any other serious organization theory. On these grounds, the VSM draws extraordinary heuristic power for the diagnosis and design of all kinds of organizations – if the claim is justified.

3.2 Basic structural configuration

According to the theory of the VSM, an organization is viable if, and only if, it commands a set of management subsystems, the functions and interrelationships of which are defined precisely. More detailed expositions of the following are available in the original literature (Beer, 1979, 1981, 1984, 1985) and in methodologically oriented works, e.g. those of Espejo and Reyes (2011), Pérez Rios (2012) and Schwaninger (2009). For a complete and succinct presentation of the theory of the VSM, see in particular Beer’s study (1985).

According to the claim formulated above, a company is viable if, and only if, it has a system of management functions and interrelationships, which are precisely specified by the theory, as follows:

The foundations of a viable system are its basic units (“operations”), in which the purpose of the organization is fulfilled. Examples are the business units of a firm, the nation-states of a federation, the nations of a continent, etc. These basic units absorb the complexity
of the environment to which they are exposed. For that purpose, they need a high degree of autonomy.

In brief, the necessary and sufficient components of management and governance, for the achievement of viability, are outlined here (see also diagram in Appendix 1)[6]:

- **System 1** — “Implementation”: Management capacity of a basic unit, local optimization of daily business.
- **System 2** — “Coordination”: Attenuation of oscillations between the basic units; reinforcement of self-regulation, transduction, i.e. encoding and decoding of messages across boundaries of subsystems, translation of languages of the different basic units into a common code.
- **System 3** — “Integration”: The operative management of the organization as a whole, with supporting functions such as human resources and finance. Establishment of an overall optimum (in contrast to the local optima).

**Interaction Systems 1-3 (vertical channel):** Responsibility and accountability, negotiation of goals and resources, management by objectives, budget control, management by exception, interventions (only if the cohesion of the whole is threatened).

**Interaction Systems 1-2-3:** Attenuation of complexity by rule-based coordination, filtering of messages to the attention of System 3, communicational coping with complexity and enhancement of organizational cohesion.

- **System 3** — “Auditing”: Supplementation and validation of the information flowing on channels 1-3 and 1-2-3, by means of activities of auditing/monitoring via direct access to the basic units. For example, internal and external auditing functions and informal communication.
- **System 4** — “Intelligence”: Comprehensive orientation toward the overall environment and the long-term future, strategic exploration of potential action spaces. Development and strategy functions.

**Interaction Systems 3-4:** Interplay of short- and long-term, as well as internal and external perspectives, processes of strategy development.

- **System 5** — “Ethos”: Balancing of present and future, equating internal and external perspectives in a very large time horizon. Ethos of the whole system, normative management, normative governance; often codified in a corporate charter, mission statement or the like.

**Interaction Systems (3-4)-5:** Moderation of the interaction between Systems 3 and 4, resolution of conflicts between the different logics of those systems. Mainly: ensuring the balance among the logics of Systems 3 and 4.

In addition to the management functions specified until this point, viable systems invariably show certain alerts (alarm signals) that refer to existentially critical situations. These “algedonic signals” (from Greek “álgos” – pain, and “hēdône” – pleasure) serve the prevention of damage. They announce threats, but also extraordinary opportunities, from the basic units directly to the metasystem. This way a crisis management (or a special arrangement for taking the opportunity) can be triggered immediately.

The issues of governance arise mainly from the interactions among senior management, shareholders and boards of directors (Cochran and Wartick, 1988). Hence, these issues are primarily tied to the “metasystem,” the complex of Systems 3, 4 and 5 (Appendix 1).
So much for the necessary and sufficient structural components for the management and governance system of a viable organization.

3.3 Principle of recursion
Together with the structural configuration just outlined, the core of the theory of the VSM contains an organizational maxim: the principle of recursion. The viability, cohesion and self-organization of an organization are based on this configuration being present recurrently in the primary units of all levels of the organization, e.g. firm – division – business unit, etc. In other words, viable systems are structured recursively. Using a generic expression:

\[ R_z \subset R_y \subset R_x \subset R_w \]  

(1)

This formula expresses the sequence of the basic units at the different levels of recursion \( R \) from levels \( x \) to \( z \). The units of the lower planes are embedded in the units of higher planes:

\[ R_z : R_y : R_x : R_w \]  

(2)

Viable systems are fractals, i.e. they are self-similar in that their basic structure repeats itself along the different levels of recursion.

A recursive structure embraces autonomous units within autonomous units. Hence, a viable organization consists of viable units and is itself embedded in more comprehensive viable units (see diagram in the Appendix 1). Each one of these units – insofar as it fulfills the task of the organization, not being limited to the service or support to that “production” – is a structural replication of the whole into which it is embedded: it can manage the processes for whose sake it exists, from beginning to end, as it owns all the described components of a management system. The autonomy of these units is, in principle, high but limited by the need for cohesion of the larger whole.

The combination of the logical hierarchy of the control functions 1-5, and the recursive embeddedness of the primary units, results in the metasystem (Systems 3, 4 and 5) of a given level of recursion being, at the same time, System 1 of the next higher level of recursion (see Appendix 1).

3.4 Diagnosis and design with the viable system model
Deficits in the fabric outlined, for example missing structural components, insufficient capacity of or deficient interaction between the components, will impair or jeopardize the viability of the organization. Two examples, often Systems 2 and 4, are developed insufficiently or not optimally. A defective System 2 will impair the viability of an organization. Similarly and a fortiori, to lack a System 4 with reasonable capacity can be threatening for a firm. There exist many companies that are still earning good money, but are already dead from a strategic point of view.

These kinds of structural deficits can normally be diagnosed with relative ease and sufficient precision, with the help of the VSM. Hence, the model is a powerful instrument for diagnosis. On the basis of diagnostic insights gained, sound organizational configurations can be found and achieved, i.e. the VSM is also a design model of high potential.

The question on how to structure organizations for sustained viability and prosperity is a burning issue of our time. The VSM gives an answer, which is beyond the reach of short-termist recommendations and buzzwords of all kinds. It conveys an orientation for the long term, giving a guideline how to build structures enabling viable systems.
4. Applications of the viable system model

The use of the VSM will now be illustrated. First, we give an overview of the VSM applications documented in the literature. Then we will use two classical case studies out of a large number of applications in which the author acted in the function of a consultant[7]. In each case, both diagnosis and design will be paired: the quality of a design depends crucially on the accuracy of the diagnosis. The first case will be documented in detail, and the second case in a briefer fashion, by avoiding repetitions.

4.1 A survey of viable system model applications

The following survey should provide a broad overview of the spectrum of applications realized until now and documented in the literature.

The VSM is based on Stafford Beer’s theoretical writings, namely, those of Beer (1985, 1984, 1981, 1979) and other sources[8]. A great part of the literature has focused on the aspects of applying the model, namely, a reasonable amount of case studies.

Many of the published cases refer to corporations (Beer, 1979; Espejo and Harnden, 1989; Brocklesby and Cummings, 1996; Gmür et al., 2010), or parts thereof (e.g. knowledge teams, in: Frost, 2005), public organizations (Beer, 1970; Leonard, 1989), local or regional settings (Türke, 2008, Schwaninger, 2012; Espinosa and Walker, 2006), nations (Beer, 1989; Willemsen, 1992) or multiple recursions (Beer, 1979; Schwaninger, 2015).

Several subject matters have been addressed, e.g. sustainability (Espinosa and Walker, 2006; Espinosa et al., 2008; Schwaninger, 2006b), the analysis of information (Preece et al., 2013), disaster management (Reissberg, 2011), urban development (Pérez Ríos and Martinez Suárez, 2012), project management (Schwaninger and Körner, 2003), virtual organizations (Schwaninger and Friedli, 2011) and the potential of the VSM for organizational diagnosis and design (Willemsen, 1992, Schwaninger, 2006a, 2012). Other authors have focused on the methodology for the application of the VSM (Espejo and Harnden, 1989; Espejo and Reyes, 2011; Pérez Rios, 2012), some on combinations of the VSM with other methodologies (Elezi et al., 2014; Herrmann et al., 2008; Schwaninger and Pérez Rios, 2008).

Normally, these cases do not obey a testing logic. They are rather motivated by a desire of documenting applications or of merely convincing others of the utility of the model. Such cases of “tests” via confirmation emanate from an interest to know, whether the theory works or not. They are a necessary complement to tests following a falsification logic. Studies about the VSM, which adopt Popper’s falsification criterion (Popper, 2002/1959), have been rare; one of those will be documented in the next section.

4.1 Case 1: development of a governance system

This case is about a health services organization. The author coached a corporate development project with that enterprise. This case was chosen to be reported here because it is one of the few instances in which a systematic follow-up was realized five years after the project. The successful transformation of the firm under study will be expounded from the viewpoint of corporate governance, and with a retrospective evaluation in the light of the VSM.

4.1.1 Initial situation. H&R is a provider of health services in a well-known resort in southern Germany. At the time of the project, it owned a share of 50 per cent of the local bed capacity. The company consists of three clinics, a hotel, plus a comprehensive bathing and health facility. The resort has a salt spring, which provides the strongest brine in the country. Moreover, the little town enjoys a high reputation for the cure of rheumatic and bronchial diseases, as well as psoriasis. Clients are mainly patients financed by public insurance providers.
H&R approached the consulting institute of which the author was a member at the time. The company was in good condition, but there was trouble ahead. Changes in the regulatory apparatus of the health sector were due, and this would lead to a crisis of health resorts in general. Eventually, H&R and the consultants agreed on realizing a project to work out a corporate policy and a strategy that would strengthen the viability of the firm.

4.1.2 Organizational diagnosis. Early on, a diagnosis of H&R in terms of the VSM was realized. It showed that the “inside and now” (Systems 1, 2 and 3) was indeed solidly embodied and well-functioning. However, there was clear evidence that Systems 4 and 5 were weak to non-existent. Pragmatically speaking, the company “had management, but not governance.”

The operative management of the overall company – in the sense of System 3 – was essentially provided by two persons, the general manager and his deputy, plus a small central staff around them. It appeared to be flawless, working very efficiently. However, a management for the long term and the environment at large – in the sense of System 4 – did not exist, except in a rudimentary and informal way. There must have been people who reflected about the “outside and then” of the company, otherwise the general manager would not have perceived the environmental changes and taken the initiative for the corporate development project. What the company lacked was an organ that dealt with these issues on a continuous basis.

As far as the normative management is concerned, i.e. the ethos of the organization – in the sense of a System 5 – the situation was different. There was a pertinent body – the supervisory board – which had the task of deciding the ultimate questions of the company:

Q1. What was its identity?
Q2. Which were the basic values to which it adhered?
Q3. Which were the corporate purpose and mission?
Q4. What was the corporate policy?

The board comprised an interdisciplinary set of highly respected persons from the community, including the mayor of the city. These people met on a regular basis. The meetings had a rather formal character. There were only few substantive discussions, as the operations were under control while strategic development was not a subject that would be raised regularly. As a consequence, no substantial tensions or conflicts between the “inside and now” and the “outside and then” appeared. System 5 had the role of a moderator between Systems 3 and 4. As System 4 barely existed, there appeared to be no need for a moderating function. Hence, System 5 collapsed into System 3.

The general manager’s hunch that the firm, even though it was functioning well at the moment, was heading for a crisis, was thus confirmed on structural grounds.

4.1.3 The corporate development project. A joint corporate development project was set up with the general manager in charge and two external consultants – the author and one of his colleagues. The main activities of the project were six workshop days, completed within six months. Before and after the workshops, additional analytical work had to be done.

An outstanding group of people collaborated in these workshops:

• all members of the Board, including the mayor of the town;
• the general manager, his deputy and two of his central staff; and
• the managers of the five sites of the company.
It must be noted that the management of a clinic is normally constituted by a medical superintendent and an administrative director. For this reason, the group assembled for the strategy project was an inter-disciplinary one with people of medical, commercial-administrative and technical backgrounds. The workshops included demanding analytical work as well as a weighty decision process. A fundamental insight generated was about the nature of the place: it was not a tourist destination but a health resort. That was a decision clarifying the organizational identity. Also, the principles and values of the company were verbalized and sharpened.

One important decision was the inclusion of a hitherto unattended syndrome into the portfolio of indications attended to by the H&R facilities. Another decision was for a strong ecological commitment, including a substantial upgrade of the outdoor facilities, necessarily accompanied by a reduction of concrete and asphalt structures (“green in, grey out”).

One astonishing feature of the project was the extremely fertile collaboration across disciplines. It was especially novel to see medical doctors working at strategic plans and programs, which had little to do with medicine.

In these workshops, Systems 4 and 5 of H&R were formed. Both the members of the strategy team and the board continued that work in the years thereafter. A system of corporate governance was in place. This came out clearly in the follow-up.

4.1.4 Follow-up. One year later, the resort crisis came as foreseen, but the difference for H&R was that, on the basis of the corporate development project, it weathered the storm quite well, at least better than most other such resorts.

Five years after the project, a follow-up including multiple interviews and document analysis, and local inspection, was carried out and minutely documented in a scientific report[9]. According to the data, the company prospered in the years after the project. Besides consolidating and expanding its activities, it increased both value potential and operating performance. The value of the company grew vigorously, more exactly, by a factor of 2.5 within five years. In addition, the firm contributed significantly to its municipal environment. It was that strategy project, which pointed the way for H&R’s prosperity in the years thereafter.

However, this evolution was not free of difficulties. During the first three years, H&R suffered serious decreases in revenue. Yet, governance was effective: the company adhered to its strategic orientation unswervingly, despite enormous difficulty in staying the course. Despite temporary operating losses, investment in the development of value potentials continued. This went so far that the corporation realized the largest investments during a period in which, from an operating point of view, it was faring worst. Management was not thrown off course by the slump, nor did they overreact. Without the normative guiding principles and the strategic orientation created beforehand, this perseverance would most probably have been impossible.

4.1.5 Conclusions. In sum, H&R had put a system of governance in place. With the new System 4, the company had formed an organ to deal with the strategic issues. But it had also reactivated the board in its normative function and clarified the identity and ethos of the organization (System 5). All of this proved to be very effective.

At the outset, there had not been System 4, and for that reason, whatever there was of System 5 collapsed into System 3 (Figure 3). In other words, a dialog about the future of the company was lacking, with the consequence that there was no role for System 5, whose main task would be to moderate the interaction between Systems 3 and 4.

The new strategy team spoke a language, which was new to the company – the language of the long term. The innovation consisted in the fact that from then on discussions about
quarterly results (Systems 1, 2 and 3) were separated from those about strategic development (System 4). In cybernetic terms, System 5 ceased to collapse into System 3. System 5 was activated in the new approach to managing the firm. Now, contrary to the past, both the “inside and now” as well as the “outside and then” were anchored in the organization.

The project reported here was not just a one-off job. On the contrary, Systems 4 and 5 work initiated therein was continued internally over the following years. The resort as a whole and the company continued a solid and healthy development. H&R expanded the salt water pools, created quiet zones, parks and gardens and new clinical facilities. An additional indication was taken on in the business portfolio: disturbances of language and voice, with new and unique forms of treatment. The therapy center was expanded and a modern sanatorium for rheumatic indications was added to the extant facilities.

In light of the follow-up interviews with the executives of H&R, it is very reasonable to assume that much of this progress would not have happened without the corporate development project. The project had triggered crucial decisions and, perhaps most important, it had led to an adequate structure for dealing with the “outside and then” in a systematic fashion. The interdisciplinary strategy team developed requisite variety for dealing with the complex challenges ahead.

To conclude, the H&R case impressively demonstrates the vital importance of a metasystem with an appropriate structure and sufficient capacity for a functioning corporate governance.

4.2 Case 2: enhancing organizational intelligence and cohesion
This is the case of Chemex, a small corporation in the chemical industry. It was made up of three companies, the largest being in Switzerland. The second company was an acquisition made in England, and the third a joint venture in the USA. Chemex produced anti-corrosives, adhesives and insulation materials.

The founder and chief executive officer (CEO) of the company was an extraordinarily dynamic person, a high-energy player developing the company at a vigorous pace.

He sought the support of consultants for his efforts to build up the organization.

4.2.1 Organizational diagnosis. In retrospect, Chemex showed the following picture, if we look at it through the lens of the VSM. All three companies were well managed and healthy. Their heads reported to the corporate management along the System 1-3-axis. However, the corporation as a whole did not reveal much cohesion as System 2 was almost nonexistent.

Mutual coordination and alignment among the three companies were weak. This is expressed by the broken lines representing System 2 (Figure 4), although System 2 was not
completely inexistent. There was, for example, a technological coordinator who provided the exchange of recipes and people between the laboratories in Switzerland, England and the USA. Nevertheless, there was no operative planning and information system.

In contrast, System 3* manifested itself to a significant albeit incomplete extent: the CEO travelled a great deal and had therefore frequent contact with the basic units. He knew quite well everything going on anywhere in the company.

An algedonic channel for signals about instabilities that would add something to the 3*- System was not actually discernible, as major crises had not occurred. One may assume that such an algedonic function would materialize – as direct alerts of the CEO – if great instabilities would arise.

System 4 was almost non-existent, and so was System 5. Corporate governance then took place punctually and geared by the intuition of the CEO.

While each of the three companies revealed a strong knowledge of and concern for its own environment, hardly any systematic examination of the environment of the corporation as a whole took place. Admittedly, the CEO was interested in these issues, but he did not pursued them consistently nor were the signals coming from the outside and concerning the long term gathered and processed coherently. Also, corporate ethos, basic values and norms were hardly perceptible or, if so, debated.

The main issue for which the CEO was seeking support was to enhance the cohesion of the company. He felt that although the three units were very dynamic, the whole was in danger of falling apart. The second issue the CEO was concerned with was that a process of strategic and normative reflection, involving more employees of the company, had to be started.

4.2.2 The corporate development project. In this situation, a corporate development project was started. It was initiated and coordinated by the CEO himself, with this author and a colleague as external partners. The project had two phases, which were mastered in short time, thanks to demanding goals and exceptional commitment on the part of all those involved in the project.

The first phase was the formation of a strategy team of 12 persons from all three companies and the corporate headquarters. A strategy and a corporate charter were elaborated in a series of workshops. This way Systems 4 and 5 were created and installed within less than half a year and they functioned fully from the beginning. In an immediately subsequent second phase, a corporate planning and reporting system was established. This was a major reinforcement of the corporation’s System 2. In a planning workshop, the participants accomplished the full planning for the next period as well as the first round of an management by objectives process for the coming year. It was very helpful that all the
planning templates were drawn up in two languages, English and German. This corresponded to the requirement that System 2 should translate the languages of the basic systems into a common code. Also, the direct relationships among the three companies (squiggled lines in Figure 4) were activated; the conversations in the workshops giving a strong impetus.

4.2.3 Follow-up. Conversations with one member of the executive board provided feedback about one year after the project. The governance system was in place and it worked. The corporate development continued in the way it had been started in collaboration with us. Over roughly four years, the company evolved splendidly. Thereafter it was acquired by the market leader of the main business of Chemex.

4.2.4 Conclusions. The main objective, to enhance the cohesion of the corporation, had been fully achieved. The corporate development project had strengthened the company and enhanced organizational learning. In addition, when the project was concluded, Chemex had a much clearer strategic outlook, and a relatively precise consciousness about its identity and organizational ethos (values, mission and principles). Beyond that, it had established a full-fledged governance function.

5. Theoretical claim and empirical evidence
This article approaches the VSM from a perspective of social science and therewith empirical science. Hence, it must be emphasized: we cannot and do not claim to “prove” the model to be “right,” because proof is a matter of the formal sciences only. We can only try to falsify it, and see if it fails or not (Popper, 2002/1959).

The cases presented above suggest that the model has utility. If one intended to test the validity of the model, the relevant question was, “Does the VSM do justice to its theoretical claim?”

This had never been examined scientifically, except the numerous case studies, which have been documented as shown. The result in these cases was invariably, that the model works and is very useful.

The author found that a more extensive test was necessary. Two studies from the author’s research group had attempted to study the issue on the basis of samples transcending the single case study (Frost, 2005; Crisan Tran, 2006). By and large, these works supported the theoretical claim of the VSM, albeit on a very limited base of data. Hence, our intention was to complement that earlier work by means of an empirical study on a broader basis. The question posed at the outset was whether the VSM can be refuted, and if not, to what extent it is corroborated by the data.

We tested the model using a relatively large sample: a survey was realized. The details of the research project, its strengths and limitations are documented in Schwaninger and Scheef’s study (2016). This was our general working hypothesis: “In the sense of the VSM, the better the management system functions, the stronger is the viability of the respective organization.”

Our test examined the association between the structural preconditions according to the VSM and the degree of viability. A set of specific hypotheses was formulated (Appendix 2). For details, see Schwaninger and Scheef’s study (2016). H1-H5 refer to the single structural components of the VSM, i.e. Systems 1-5. The test is whether the strength of a component is associated positively with the viability of the organization in focus. H6-H8 deepen H1-H5: instead of an analysis of the association of the strength of a component with an organization’s viability, they focus on how the frequency of strongly developed components of the management system are associated with the constructs measuring viability. We used a complex construct of organizational culture as a surrogate for viability[10].
Data were collected from mostly higher and top managers from the German-speaking countries, including chief executive officers and owners of companies (349 completed questionnaires, 261 of which met our quality criteria, i.e., they were usable for the data analysis and did not have missing data).

The statistical results are summarized in Table I.

Table II provides a summary of the statistical results concerning \(H_1\)-\(H_5\). As shown in Table II, all components, with one exception (System 3), show a significant effect in direction of a culture of viability. The construct “organizational culture” is, with high significance, a function of the degree to which Systems 1, 2, 4 and 5 are developed. In other words, \(H_1\), \(H_2\), \(H_4\) and \(H_5\) are clearly supported, whereas \(H_3\) is rejected. The negative relationship between Component 3 and organizational culture is surprising at a first glance.

As one potential explanation for the lack of support of \(H_3\), we surmise that the negative impact of System 3, counter to superficial interpretation, does not reflect a loss of importance of the central operative steering function. A more appropriate interpretation would contend that central operative management, in today’s companies, has adopted alternative organizational forms, e.g. team-based, distributed or virtual structures. In other words, one can presume that System 3 has not become less important, but that it has evolved new structural solutions. New ways of capturing these should be developed in future questionnaires.

Tables III and IV show a summary of the statistical results concerning \(H_6\)-\(H_8\). The results of our analyses lead to the following conclusions. The more the components of the management system show a high level of development, the greater are the values for organizational culture qua viability (Table III). Thus, \(H_6\) is supported. Furthermore, the higher the overall functional level of Systems 1-5, the higher will be the effect on organizational culture qua viability (Table IV). Hence, also \(H_7\) is supported. Finally, higher deviations among the functional levels of Systems 1-5 do not entail lower or higher levels of organizational culture qua viability, because the impact of the standard deviation of the components is not significant (Table IV). Therefore, \(H_8\) is not supported. Yet, as the result is non-significant, greater or lower deviation among the functional levels of the components also does not harm the organizational culture.

Our analysis has given significant results for six hypotheses; one was neither supported nor rejected, and one was rejected. To summarize, we did not succeed in falsifying the VSM. At the contrary, the evidence confirms the model’s theoretical claim as justified undoubtedly.

6. Critique of the VSM
In the literature on applications of the VSM – to the knowledge of the author – hardly any accounts of failures have been published. The whole literature enumerated in the preceding section is about successes. Nevertheless, the theoretical discourse has brought forth several criticisms. We will provide a summary (Jackson, 2000, 2003).

This roundup should be an assessment of the VSM, not a list of complaints or objections. As criteria for our assessment, we will use rigor and relevance (Gulati, 2007).

On the strengths and advantages of the model: given the justification of its high theoretical claim, as reported above, the VSM embodies an outstanding conceptual device for organizational diagnosis and design. As a generic model, it holds for all kinds of organizations, private, public, large and small.

The model has methodological rigor: grounded in Ashby’s Law, it offers a well-founded structural framework for dealing with complexity. On the basis of the principle of recursion, the dealing with complexity is activated precisely where the complexity emanates. This
<table>
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<th>Component</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<th>8</th>
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<td>8</td>
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<td>0.61***</td>
<td>0.40***</td>
<td>1.00</td>
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<td>9</td>
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<td>0.51***</td>
<td>0.36***</td>
<td>0.43***</td>
<td>0.48***</td>
<td>0.47***</td>
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<td>-0.08</td>
<td>-0.03</td>
<td>-0.05</td>
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<td>0.03</td>
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<td>0.04</td>
<td>0.10</td>
<td>1.00</td>
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**Notes:** Standardized beta coefficients; * < 0.10; * < 0.05; ** < 0.01; *** < 0.001
way, governance and management are not an artificially imposed function, but a system property, which is integrated pervasively across the whole organization.

The VSM also conveys a conceptually founded architecture for the design of organizations according to the principles of autonomy, decentralization, participation and ultimately democracy. In addition, it underpins – from a structure-theoretic stance – the

<table>
<thead>
<tr>
<th></th>
<th>All firms</th>
<th>Large- and medium-sized firms</th>
<th>Small firms</th>
<th>Hypotheses</th>
</tr>
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<td>1.924***</td>
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<td>Firm size</td>
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<tr>
<td>Component 1</td>
<td>0.154***</td>
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<td>0.165*</td>
<td>H1 supported</td>
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<td>Component 2</td>
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<td>0.190**</td>
<td>H2 supported</td>
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<td>-0.003</td>
<td>-0.190*</td>
<td>H3 rejected</td>
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<td>Component 4</td>
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<td>0.163*</td>
<td>0.092</td>
<td>H4 supported</td>
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<td>Component 5</td>
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<td>0.183*</td>
<td>0.304***</td>
<td>H5 supported</td>
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<tr>
<td>N</td>
<td>261</td>
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<td>80</td>
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<tr>
<td>$R^2$</td>
<td>0.485</td>
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Notes: standardized beta coefficients; **** < 0.10; * < 0.05; ** < 0.01; *** < 0.001

Table II. Statistical results for H1-H5

<table>
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<th>Hypotheses</th>
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<tr>
<td>Firm size</td>
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<td>0.037</td>
<td>0.102 ****</td>
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<tr>
<td>Number of strongly</td>
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<td>0.456***</td>
<td>0.496***</td>
<td>H6 supported</td>
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<td>pronounced components</td>
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<tr>
<td>N</td>
<td>261</td>
<td>181</td>
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<tr>
<td>$R^2$</td>
<td>0.278</td>
<td>0.219</td>
<td>0.404</td>
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</table>

Notes: Standardized beta coefficients; **** < 0.10; * < 0.05; ** < 0.01; ***< 0.001

Table III. Statistical results for H6

<table>
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<tr>
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<th>Large- and medium-sized firms</th>
<th>Small firms</th>
<th>Hypotheses</th>
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</thead>
<tbody>
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<td>Constant</td>
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<td>0.037</td>
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</tr>
<tr>
<td>Firm age</td>
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</tr>
<tr>
<td>Firm size</td>
<td>0.063***</td>
<td>0.119 ****</td>
<td></td>
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<tr>
<td>Overall level of</td>
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<td>0.176****</td>
<td>H7 supported</td>
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<td>components</td>
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<tr>
<td>Standard deviation of</td>
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<tr>
<td>components</td>
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<tr>
<td>$R^2$</td>
<td>0.421</td>
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</table>

Notes: Standardized beta coefficients; **** < 0.10; * < 0.05; ** < 0.01; ***< 0.001

Table IV. Statistical results for H7 and H8
necessity for humanistic work design and the realization of human potential. Under these aspects, the model’s heuristic power has been asserted to excel traditional models, e.g. the human relations and the contingency approaches (Jackson, 1985). The VSM abides by the rationale of modern organization science and enables a conclusive integration of different organization-theoretic approaches.

Finally, the VSM enlarges the perspective of the organizer: the environment or milieu is marked explicitly in the organization chart. The special graphic mode makes rich structural diagrams possible: the sketches visualize the environment and its interrelationships with the organization, they make information flows transparent and they allow for grasping multiple organizational levels with their relations in one and the same graph.

Given these strengths and advantages, the model has been used frequently and it seems that the amount of applications is growing[11]. This indicates that the VSM is relevant.

Now to the limitations of the VSM: a frequently advanced argument imputes that the model would not consider the goal-oriented, purposeful nature of individuals in organizations, but conceive of them as essentially exogenously determined, purposive objects. A related allegation is that the model would not account for the human, “soft” factors. Indeed, the model is not psychologically oriented, but it is structuralist. The humanistic content of Beer’s work, related to the VSM, is in the high degree of autonomy attributed to the members of the organization and in aspects such as self-reference, perception and the roles of individuals (in particular Beer, 1979). Beer’s theory does nowhere allege that individuals (or organizations) be exclusively determined from outside. It rather conceives of individuals as self-determining, reflexive subjects.

Certain authors criticize the analogy with the human brain, which they consider misplaced (Amey, 1986), as the parts of the organization are purposeful. However, Beer fully acknowledges the purposefulness of individuals (and subsystems of social systems in general), who have their own goals and values: the parts of an organization have their own metasystem. This is a desideratum and it is part of the theory of recursive organizations (Beer, 1979).

Another argument insinuates the aspect of power to be neglected in the VSM. Indeed, one cannot find comprehensive tracts about the theory of power there, but Beer pleads for humanistic work design, well-being and “people’s growth” (Beer, 1979, p. 479), and he already took up the issue of “empowerment” early on (1983a). Beer also conceptualizes the power of organizations as the “ability of the organization to gather itself together in an effective identity, to act as a unified whole (Ibidem: 417f.).

Finally, the main critique as formulated by Ulrich (1983), e.g. disparages the VSM as the epitome of a “sheer cybernetic logic,” a crass hierarchy which, in the critic’s view, produces inhuman conditions, incapacitating and tyrannizing humans. The model is charged to be a mechanistic instrument of domination or even suppression (Ulrich, 1981). This kind of use of the model cannot be ruled out categorically, but according to Beer (1983b), precautions can be provided to minimize the risk of subversion. We purvey a number of counter-arguments (Jackson, 2000):

- The VSM is closer to a reticular structure than to a one-dimensional hierarchy, as it combines the concept of logical hierarchy (Systems 1-5) with the concept of recursive structuring.
- Normally, in the top organ of management (System 5) of a given level of recursion, the stakeholders of the respective system are contained, often as elected representatives.
- The recursive levels are interpenetrated by each other, in that the members of the downstream levels are represented in the management organs of the upstream
levels, and vice versa. For example, the metasystem (3-4)-5 of each unit of a given unit of recursion is System 1 of a unit at the next higher level of recursion. This way, imbalances of power between “below” and “above” cannot be eliminated, but at least mitigated by negotiation. In addition, influence by information can be achieved via six channels (for details, see Beer, 1985).

- In modern organizations, the relationships between the units carrying out the tasks are multidimensional, materializing in heterarchies, teams, etc. This enhances participation and a balancing of bottom-up and top-down leadership. This can be shown for the case of the metasystem (Systems 3-5). Beer (1994) designed a protocol for “democratic organization” denominated “Team Syntegrity.” His aim was to structure the 3-4 homeostat (and also the (3-4)-5 homeostat) with the requisite variety for dealing with the present and future of an organization simultaneously. Team Syntegrity provides a methodology, which enables the efficiency and effectiveness of large groups via a democratic path. It has been applied extensively, with broad success (for an overview, see Schwaninger, 2009).

7. Implications and conclusion

We have made an attempt to revisit the VSM and discuss it from both the theoretical and the empirical standpoints. The theoretical discussion has led us from a presentation of the theory to an analysis of the critique of the model as formulated in the literature. The empirical part has shown samples from qualitative and quantitative studies.

The evidence evinces that cybernetic theory provides us with effective devices for the governance of organizations, to make them intelligent and viable. We have focused on the VSM, which has proved to be a powerful means of navigation for organizations of all kinds, public or private, large or small. The results of our study indicate that the claim of the VSM – to provide the necessary and sufficient precondition for the viability of any organization – is justified. We have not succeeded in falsifying that claim on empirical grounds. This corroborates the effectiveness of the model.

Furthermore, our theoretical discussion of the critique of the model has not disclosed any significant limitations to the model as such or its applications. In conclusion, organizers can benefit strongly, if they base the diagnosis and design of organizations on the VSM. The theory of the VSM endows both practitioners and social scientists with a precious, effective conceptual device to enable better organization, governance and management. Any application of the model can activate a huge potential for the improvement of organizations. This is the implication of our study.

In its synthesis, this study strongly corroborates the VSM with its underlying theory. This result should encourage practitioners to apply the model to their organizations and researchers to study and test it further. The exploration we have conducted was only a first take. We have already invited the members of the community of organizational cybernetics to continue the empirical line of inquiry (Schwaninger and Scheef, 2016).

The long history of applications since the invention of the VSM corroborates: this model is above the fashions and buzzwords, which supersede each other hastily in discussions about management and governance. To use a colloquial term, the VSM enables “intelligent organizations,” pointing the way to their viability, adaptation and learning. The VSM conveys a durable, reliable knowledge. That knowledge is slowly bearing fruit in the world of social systems. The model is available: a huge potential for the improvement of organizations can be activated.
Notes

1. We use both terms *management cybernetics* and *organizational cybernetics*, in this article, when we refer to the application of cybernetics to organizations and management.

2. Terms used for *organizational governance* in specific contexts are *corporate governance* and *public governance*.


4. Participation through stakeholder ownership and control is essential for an effective governance, as has been asserted theoretically and confirmed empirically (Porter, 1992, Turnbull, 1997).

5. “Viability” of a system is here defined as the maintenance of its separate existence (Beer, 1979, p. 113).

6. In the following, we are using “component” and “system” (here in the sense of subsystem) as synonyms.

7. The names we are using for the companies are fictitious.

8. It would be beyond the reach of this paper to provide a complete list of these sources. Here is an abridged set of additional conceptual-theoretical references: Malik (1984), Jackson (1988), Espejo and Harnden (1989), Brocklesby and Cummings (1996), Espejo et al. (1996), Adam (2001), Christopher (2007), Hoverstadt (2008), Türke (2008), Leonard (2010). A more detailed overview has been given in Schwaninger’s study (2009).

9. This report is available from the author.

10. In our questionnaire, 11 items with regard to the construct of organizational culture were measured on an Osgood semantic differential rating scale, between polar opposites such as “open” and “closed.” These represent the dimensions of culture as indicators of viability, and are documented in Schwaninger and Scheef’s study (2016). The extremes on one end of the scale form an ideal-type of a culture of viability, whereas the extremes on the opposite end represent the ideal-type of a nonviable culture. The scale of the measurements between visualizes that “viability” is not a dichotomous concept. It is, rather, a concept of gradual manifestations.

11. We cannot prove this: even though GoogleTrend reports a record high of Google searches of “viable system model” for early October 2017, the time series recorded cover only one year, available at: https://trends.google.com/trends/explore?q=viable%20system%20model (accessed 31 October 2017).

References


Figure A1.
Detailed original drawing of the VSM

Source: Beer (1985, p. 136); drawing by Ivan Ulynov
Appendix 2. Hypothesis of the empirical study (Schwaninger and Scheef, 2016)

Hypotheses linked to the components of the model (1-5) and their interrelationships

$H1-H5$ revolve around the question of whether the theory of the VSM can be upheld:

$H1$. An organization’s strength of Component 1 is positively associated with its viability.

$H2$. An organization’s strength of Component 2 is positively associated with its viability.

$H3$. An organization’s strength of Component 3 is positively associated with its viability.

$H4$. An organization’s strength of Component 4 is positively associated with its viability.

$H5$. An organization’s strength of Component 5 is positively associated with its viability.

Overarching $H6-H8$

$H6-H8$ deepen the topics of $H1-H5$. Different from the analysis of the levels of development (also: “functional levels”) of the individual components, as carried out here, we are now looking at the whole of the components:

$H6$. The number of strongly developed components is positively associated with the viability of the respective organization.

In this hypothesis, we address the number of components that show high values, not values of individual components, as a factor of viability. Each component was classified as high and coded as 1 when the value exceeded 3 (out of a five-point scale) and coded as 0 otherwise. The final measure was a count variable.

$H7$. The overall level of development of all components is positively associated with the viability of the respective organization.

Here, we look at the average of all values for the development of Components 1-5, as a source for increasing viability:

$H8$. The variance among the values for the individual components is negatively associated with the viability of the respective organization.

This hypothesis assumes that big differences in the values for Components 1-5 result in lower viability, and vice versa. These differences were measured as the standard deviations between the values of the five components.

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Improving managers’ intelligence through Systems Thinking

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Abstract

Purpose – Accepting the assumption that our intelligence depends on the ability to construct models which may allow us to acquire, update and transmit our knowledge, this paper aims to highlight the role of Systems Thinking in developing the “intelligence” of managers for all types and sizes of organization.

Design/methodology/apprachor – Four relevant contributions for improving the “intelligence” of managers will be examined: the ability to understand and model dynamic systems, the structure of Control Systems, the rules of the decision-making process and the identification of systems archetypes.

Findings – The paper will show that Systems Thinking, through the logic of Control Systems, offers managers a comprehensive representation of the problem-solving and decision-making processes, teaching them how to distinguish problems from symptoms and to acquire a leverage effect. Additionally, Senge's system archetypes will be presented and new archetypes will be added to Senge's list.

Practical implications – The viability of every organization and its effective resilience and survival make it more than ever necessary for managers to adopt Systems Thinking, not only as a technique but also primarily as a discipline for efficient and effective thinking, learning, communication and explanation with regard to the dynamics of the world.

Originality/value – The message of the paper is that by continually applying the rules and language of Systems Thinking, managers develop the capability to continually adapt their models to the dynamics of the world, increase their learning capacity and better gauge their consequent judgments, decisions and behavior, thereby removing the mental impediments to intelligence (inappropriate mental models, defensive routines, judgmental biases, rules, etc.).

Keywords Systems thinking, Control System, Laws of Systems Thinking, Managers’ intelligence, Problem solving and decision making, System archetypes

Paper type Conceptual paper

1. Introduction: the power of Systems Thinking

Let us clarify, first of all, what we mean by understanding, learning and intelligence, as this is the prerequisite for introducing the contributions of Systems Thinking to managers’ intelligence.

The psychological core of understanding, I shall assume, consists of having a “working model” of the phenomenon in your mind (Johnson-Laird, 1983, p. 2).

[... “understanding the world” (comprehending) means in fact being able to construct coherent and meaningful mental and formal models – that make up our “knowledge” – which allow us to form and transmit new knowledge (Mella, 2012, Ch. 1).

Intelligence may be conceived as the ability to rapidly and efficiently construct or update the models of knowledge and arrange them into coherent “bodies of knowledge” and to quickly
learn to use them to survive in a changing world. Intelligent persons understand (and comprehend) quickly and effectively (Mella, 2012, p. 3).

According to the well-known book by Peter Senge, The Fifth Discipline (1990), Systems Thinking can be viewed as one of the most powerful tools for learning and for understanding knowledge (Ackoff et al., 2010), as it teaches managers of any size and type of organization to easily develop coherent and sensible models of the dynamic and ever-changing world in which organizations operate, to help them improve their intelligence and transform their organization into a learning organization:

Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static "snapshots" (Senge, 1990, p. 68).

Systems Thinking is a Paradigm and a Learning Method. The first conditions the second. The second supports the first. The two parts form a synergistic whole (Richmond, 1994, online).

Systems Thinking does not represent a specific technique for constructing models but a mental attitude, an approach (Richmond, 1991; Meadows, 2008; Wright and Meadows, 2012; Ross et al., 2015; Hitchins, 2017), a logic and a language (Anderson and Johnson, 1997; Richmond, 2000) that obliges us to follow several basic rules. Other terms can also be used to indicate this new way of thinking. Systems Thinking is a form of thinking which has been present for some time in the literature on systems (Checkland and Haynes, 1994; Capra, 1996; Weinberg, 2001; Hammond, 2002; Midgley, 2003). In fact, in his fundamental work, General System Theory, Ludwig von Bertalanffy stated:

Systems thinking [in a very broad sense] plays a dominant role in a wide range of fields from industrial enterprise and armaments to esoteric topics of pure science (Bertalanffy, 1968, p. 3).

We can thus immediately understand that the viability of every organization public and private – be it a government, a firm, a state-owned entity or a charity – and its effective resilience and survival – as the capacity to appreciate, transform and utilize knowledge for adaptive purposes (Zahra and George, 2002) – make it more than ever necessary for managers to adopt Systems Thinking, not only as a technique but also primarily as a discipline for efficient and effective thinking, learning, communication and explanation regarding the dynamics of the world (Folke et al., 2002; Sutcliffe and Vogus, 2003; Caza and Milton, 2012).

This conceptual paper proposes a theoretical framework (as outlined by Peter Senge) that allows managers of organizations of any size, type and legal form to develop or improve their intelligence by suggesting an approach for observing and controlling the dynamic world in which they operate and for understanding the interconnections and interactions among the variables that pertain to their work (Jackson, 2003; Carsten, 2003). The managers who adopt this conceptual framework and the Systems Thinking language to construct their models will expand their intelligence and act increasingly more effectively, as they will be able to learn and act rapidly in a way that is rational and advantageous for the existence of the organization in the short and long term. In this way, managers develop the capability to continually adapt their models to world dynamics, increase their learning capacity and to better gauge their consequent judgments, decisions and behavior, thereby removing the mental impediments to intelligence (inappropriate mental models, defensive routines, judgmental biases, rules, etc.) (Sterman, 2000).

Among the numerous contributions to intelligence that Systems Thinking offers managers, the present paper will examine four which are held to be particularly important, as they are all connected and contribute to improving the capacity of managers to quickly
recognize the problems they encounter in their organizations in a rapidly changing world (Haines, 2005):

- the ability to understand and model the dynamic systems by constructing causal loop diagrams (CLDs), models which are relatively easy to produce that interconnect the variables of interest and allow for a qualitative analysis of the systems to be investigated;
- the effective representation of the Control Systems and the instruments to control the dynamics of the variables;
- the Systems Thinking principles for the problem-solving process; and
- the identification of systems archetypes, which makes problem recognition and organizational control efficient.

These contributions will be summarized in the following sections.

2. The five rules of Systems Thinking

Rather than concentrating on mathematical and technical formalism – which can be learned, if necessary, from specialist texts such as the theory of systems (Bertalanffy, 1968; Casti, 1985; Lange, 1965; Capra, 1996), introduction to systems science (Sandquist, 1985), Systems Analysis (Wasson, 2006) and control theory (Leigh, 2004; Ramage and Shipp, 2009) – Senge presents, in his excellent work entitled The fifth discipline, an intuitive way, one which could be understood by a broad readership, primarily made up of managers of any organization, consultants and corporate personnel. However, he does not provide the logical principles behind Systems Thinking. In his recent work, Systems Thinking. Intelligence in Action (Springer, 2012), Piero Mella has tried to recognize the fundamental rules and principles, as well as the cultural background of this discipline, whose logic can be summarized by this general rule (Mella, 2012): to understand the “world” it is necessary to observe the variables that represent the dynamics of its phenomena and to link them together to form unitary systems of interacting variables whose macro-dynamics, on the one hand, derive from the micro-dynamics of the component variables, and on the other condition the dynamics of these variables. In addition, Mella believes that the logical structure of Systems Thinking can be summarized in five fundamental rules, which the systems thinker must follow at all times. These rules represent in themselves the framework for constructing models that use the logic of Systems Thinking and improve the “intelligence” of managers and organizations:

First rule: if you want to describe and understand the world, you must be able to “see the trees and the forest”, to develop the capacity to “zoom” from the whole to the parts, from systems to components, and vice-versa.

This rule, which is at the basis of systems thinking, can be translated as follows: if managers want to broaden their intelligence, they “must” develop the capacity to “zoom” from parts to the whole and from entities to components. In this sense, we can say that this first rule of Systems Thinking “operationalizes” Koestler’s holonic thinking, in that it not only specifies how far the observation of the whole/part relationship should extend but also tries to identify the links and constraints that make the whole and its parts interdependent “The concept of holon is intended to reconcile the atomistic and holistic approaches (Koestler, 1967, Appendix I; Wilber, 2000). (for more: Mella, 2009; Mella and Gazzola, 2017). This rule leads to an important:

Corollary: to describe and understand the world, managers must always be aware of, or specify, their point of view; that is, the level of observation at which they choose to place themselves.

Second rule: you must not limit your observation to that which appears constant but “search for what varies over time”; it is the variables over time that interest the systems thinker.
Systems Thinking tells us to shift from a “world of objects” – whether “trees” or “forest” – to a “world of variables” that connote those objects. The objects must be “seen” as vectors of variables.

Systems Thinking also requires us to select the relevant variables and restrict their number so as to consider only those most relevant for the construction of models. This seems easier than it really is. One needs sensitivity and experience to select the truly significant variables. However, we must not limit ourselves to explicitly stating the variables we consider useful but must be able to measure the “variations” they undergo over time. The models built based on Systems Thinking rules must represent the dynamic, repetitive and interconnected systems which compose reality. Objects observed from a static vision, non-repetitive systems, individual phenomenon, simple causes, simple effects and a lack of memory are the errors Systems Thinking obliges us to eliminate:

Third rule: if you truly wish to understand reality and change, you must try “to understand the cause of the variations in the variables you observe” by forming chains of causal relationships among the connected variables while identifying and specifying:

- the processes that “produce” the dynamics in the variables and the machines/apparatuses (or systemic structures) that “produce” those processes; and
- the variables that “carry out” those processes (causes or inputs) and those that “derive” from the processes (effects or outputs) (different concepts of causality can be found in Bunge, 2009).

For simplicity’s sake, we could even call the input and output variables “causes” (causal variables) and “effects” (caused variables), respectively. Systems Thinking admits that the processes and apparatuses that produce variations can be conceived of as a black box (Wiener, 1961: xi, note 1). What is truly indispensable is to understand the rules (laws, functions, operations, etc.) by which the variations in the input variables cause variations in the output variables:

Fourth rule: it is not enough to search for the causes of the variations you observe; you must also link together the variables to “specify the “loops” among all the variations”.

Systems Thinking states that if you really want to “understand” the world and its changes, it is not enough to reason in terms of chains of causes and effects among variables; it is necessary to make any effort to observe the world in terms of circular processes or feedback loops (Roberts, 1978; Richardson, 1991), abandoning “linear thinking” (“laundry list thinking”), which only considers chains of causes and effects and becoming accustomed to “circular thinking” (loops and CLDs), thereby identifying the loops that connect the variables:

[...] according to this paradigm, each of the causes is linked in a circular process to both the effect and to each of the other causes. Systems thinkers refer to such circular processes as feedback loops (Richmond, 1993, p. 117).

Fifth rule: when you observe the world, you must always “specify the boundaries of the system” you wish to understand.

Systems Thinking is the “art of seeing the world”; to ensure that what we see has true meaning, we must focus on our cognitive interests. You cannot have a forest without boundaries.

Systems Thinking is not the panacea for solving all of man’s problems involving knowledge, judgment and behavior, but it nevertheless is an instrument that broadens man’s intelligence.
3. Understanding dynamic systems: the language of systems thinking

Systems Thinking defines “system” as a unitary set of interacting variables, interconnected by loops – capable of producing emerging macro-dynamics that do not coincide with any of the micro-dynamics of the individual variables or their partial subsystems – whose logical structure it investigates and represents (Mella, 2012, p. 21). Following the framework rules of Section 2, Systems Thinking offers managers a powerful but simple and effective language for investigating, modeling and simulating such systems, without referring to sophisticated mathematical and statistical tools.

The cause and effect relations between variables can be simply represented using arrows that unequivocally correlate their variations, as shown in the following Figure 1. Two variables have the “same direction of variation” (“s”) if increases or decreases in the former result in corresponding increases or decreases in the latter (first arrow of the model shown below). They have the “opposite direction” (“o”) if increases or decreases in the former result in corresponding decreases or increases in the latter (second arrow).

A basic loop is a circular link between two variables that can be interconnected in two opposite directions, forming a closed causal chain; a loop is compound when more than two variables are joined in a circular link. There is no limit to the number of interconnected variables.

There are only two basic types of loop:

1. **Reinforcing loops** [R], which produce a reciprocal increase or reduction – in successive repetitions of the system’s cycle – in the values of the two variables, which have an identical direction of variation: “s and s” or “o and o”, as shown in the following Figure 2.

2. **Balancing loops** [B], which maintain the values of the connected variables relatively stable, which are connected by a different direction of variation: “s and o” or “o and s”, as shown in the Figure 3.

A system of loops in which all variables are linked by arrows, without any initial and final variable, is defined as a Causal Loop Diagram (Sterman, 2000). By connecting a number of variables and determining the direction of variation we can build models of every dynamic system, keeping in mind that we must zoom in to analyze the processes in more detail to identify and connect other important variables.

The model in Figure 4 clearly shows the main variables that drive the marketing strategy.

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**Figure 1.**
Direction of variation in cause/effect relationships

<table>
<thead>
<tr>
<th>X</th>
<th>causal relationship</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>⊕ Δx</td>
<td><strong>S</strong> (same direction)</td>
<td>⊕ Δy</td>
</tr>
</tbody>
</table>

**Figure 2.**
Reinforcing loops

<table>
<thead>
<tr>
<th>X</th>
<th>causal relationship</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>⊕ Δx</td>
<td><strong>R</strong> (opposite direction)</td>
<td>⊕ Δy</td>
</tr>
</tbody>
</table>

**Figure 3.**
Balancing loops
4. Deriving two Systems Thinking laws managers must always keep in mind regarding control and problem-solving

One of the most important results of Systems Thinking is to make clear to managers that the world is made up of interconnected and interacting variables and that its understanding requires the application of the entire framework in Section 2, from which we can derive two fundamental logical laws of Systems Thinking (Mella, 2012):

(1) Law of interaction between structure and components: to understand and control the dynamics in the world, it is necessary to identify the systemic structures that make up this world:

- On the one hand, the behavior of a variable depends on the system in which it is included.
- On the other hand, the behavior of the entire system depends on its logical and technical structures; that is, on the interconnections among its component variables and on the “machines” producing their variations.

In the systems approach, the properties of the parts can be understood only from the organization of the whole. Accordingly, systems thinking concentrates not on basic building blocks, but on basic principles of organization. Systems thinking is “contextual,” which is the opposite of analytical thinking (Capra, 1996, p. 29).

Connected to the preceding law is a second fundamental law of Systems Thinking, which I shall term the:

(2) Law of dynamic instability: expansion and equilibrium are processes that do not last forever; they are not propagated ad infinitum. Sooner or later stability is disturbed. Sooner or later the dynamics are stabilized.

Operationally speaking, this law affirms that, though we are unaware or unable to observe this, every reinforcing loop is always associated with a balancing loop that dampens the expansion dynamics and vice-versa; every balancing loop is associated with some type of reinforcing loop that counters the balancing effect.

5. Control systems

Systems Thinking teaches us that the world is made up of nested systems of interacting variables that can produce ordered, coherent and useful dynamics, but also disordered, incoherent

![Figure 4. Marketing strategy](image-url)
and harmful dynamics. In the latter case, which is not an exception but rather the norm, it becomes necessary to control the dynamics of the harmful variables (Arbib, 1987, online).

All stable processes we shall predict. All unstable processes we shall control. (John von Neumann, from Dyson, 1988, p.182).

The conceptual framework of Systems Thinking produces the powerful “feedback” Control System Model (Mella, 2014), described in Figure 5, which represents an apparatus, logical or technical (algorithm or machine, rule or structure, etc.) for controlling variables of any kind, both qualitative and quantitative.

Following Figure 5, a variable $Y_t$ is defined here as “controllable” if, on a temporal (continuous or discrete) scale, $t = 1, 2, \ldots$, we can force it to assume a given value $Y^*$ (set-point), which can represent an objective, goal, constraint, or limit of $Y_t$. At time $t$, if $Y_t \neq Y^*$, we can measure a distance, gap, variance or error, which we denote by $E(Y)_t = Y^* - Y_t$.

The control of $Y_t$ is produced by acting on a control variable, or lever, $X_t$, so that the values of $Y_t$ approach $Y^*$ in an iterative process and, if the system is well designed, $E_t$ becomes zero, even in the presence of external disturbances, $D_t$. Here is how Norbert Wiener elegantly presents the idea and the function of both “distance” – that is, “error” – and the technical structure subject to the control:

Now, suppose that I pick up a lead pencil. To do this, […] our motion proceeds in such a way that we may say roughly that the amount by which the pencil is not yet picked up is decreased at each stage (Wiener, 1961, p. 7).

Using the logical language of Systems Thinking, we can easily see in Figure 5 that a Control System is a typical balancing loop (a Ring) that connects the four variables [$X_t$, $Y_t$, $D_t$, and $E_t$]; in the balancing loop, the values of the lever $X_t$ – which determine $Y_t$ in direction “s” (“same”) – do not depend on $Y_t$ itself but on the error, $E(Y)_t$, in direction “s” (the higher the error, the greater the corrective intervention of the $X$). The higher $Y_t$ is, the lower the distance (error); for

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**Figure 5.**
Standard model of a one-lever Control System

*Source: Adapted from Mella (2014, p. 70)*
this reason, there is a relation in direction “o” (“opposite”) between Y and E(Y). If we define [X] as a set of N action levers, the system is called a multi-lever Control System. If [Y] is a set of passive variables, the system is called a multi-objective Control System.

The manager of the Control System is defined (in the broadest sense of the term) as the subject (individual, group, organ or organization) that, through a series of decisions – based on his/its particular culture, preferences or program – can regulate X to change Y. The governance of the system is defined here as the process by which the objective Y* is determined.

In multi-lever Control Systems, especially those where the control levers can be activated independently of one another, the manager must first define the control strategy to be adopted, by choosing the most appropriate levers in terms of the objectives to be achieved and their urgency, together with their activation order. In addition, in multi-objective Control Systems, the control requires a governance that determines a control policy that specifies the objectives and the order of priorities, taking account of their urgency and the size of the error (Mella, 2014).

The model proposed in Figure 5 clearly emphasizes the role of the manager, as described by Beer:

If cybernetics is the science of control, management is the profession of control (Beer, 1966, p. 54).

Even more clearly, in outlining the contribution of his book, Brain of the Firm, he states:

This book is entirely concerned with the contribution which cybernetics, the science of control, can make to management, the profession of control (Beer, 1979, p. 17).

Therefore, managers must keep in mind that, although management theory today uses the term strategy in a more general sense, often including the drawing up of policy (Chandler, 1962, p. 13), the typical function of managers as “control professionals” is to translate the policies into plans and programs that identify and specify the level of objectives and constraints; set up measurement systems for the deviations (Errors) among the programmed values and those in the process of being achieved; and determine the most effective strategy for eliminating the deviations. Finally, managers must determine the size of the effectors; that is, the organizational structure that carries out the management process.

Despite the simple logic and infallible efficacy of Control Systems, Systems Thinking teaches managers to be cautious in controlling one or a few variables within a dynamic system. More specifically, managers must keep in mind that the Law of interaction between structure and components (Section 4) has three relevant corollaries:

1. It is useless to try to modify the values of a variable if first we do not understand the systemic structure of which it is a part, as the balancing loops will restore its value and the reinforcing loops will increase it.

2. Even if we are not aware of it, in every systemic context the reinforcing loops are always linked to some balancing loop, and vice-versa.

3. In observing a dynamic world, the “ceteris paribus” assumption is never valid.

This is why it is necessary to link the model of the Control System to the “problem solving model” (Figure 6); in fact, they both describe a present situation we are not satisfied with and would like to improve, shifting to a desired situation (objective) or they highlight a worrisome situation we wish to return to an optimal state (Shibata, 1998).

In other words, a distinguishing feature of a problem is that there is a goal to be reached and how you get there is not immediately obvious. To put it at its simplest, you have a problem when you are required to act but you don’t know what to do (Robertson, 2001, p. 2).
What will be presented in the next section applies to not only problem-solving (Proctor, 1999; Mayer, 1992; Harris, 2002) but also decision-making (Simon et al., 1986; Harris, 1998; Shaw, 2001).

The work of managers, of scientists, of engineers, of lawyers—the work that steers the course of society and its economic and governmental organizations—is largely work of making decisions and solving problems. It is work of choosing issues that require attention, setting goals, finding or designing suitable courses of action, and evaluating and choosing among alternative actions. The first three of these activities—fixing agendas, setting goals, and designing actions—are usually called problem solving; the last, evaluating and choosing, is usually called decision making (Simon et al., 1986, online).

6. The principles of systems thinking applied to problem solving

Referring to Figure 6, solving a problem means achieving a state \( Y^* \) considered “optimal”, starting from a present, non-optimal state \( Y \). The problem is perceived as an error between the two states, \( E(Y) = Y^* - Y \). This is not true: \( E(Y) \) is not the problem; it must be conceived of as the evident “symptom” of the incorrect dynamic of a state variable, which has departed from the optimal value. The problem-solver (that is, the manager of the Control System) must eliminate the error through decisions involving the activation of the control levers to modify the variable \( Y \), which is out of control.

The model can be applied to both artificial and natural systems.

For example, thirst represents the error \( E(Y) \) between an optimal salt/water density \( (D^*) \) and the actual density \( (D) \); this is the symptom of a serious problem we all experience when subjected to scorching heat. To get rid of the thirst, the manager must restore the correct salt/water density by ingesting water (drinking) or taking salt into the organism, if appropriate. In all respects, this represents a two-lever Control System that detects the problem and solves it, activating the “water ingested” or “salt ingested” levers. This is a natural system for most higher-order animals, who are the managers that decide which levers to activate and to what degree.
Systems Thinking warns us that a problem must not be identified with the evident symptoms, proposing the following general rule:

**General rule:** we must not limit ourselves to viewing problems as undesired symptoms of immediate causes (Ishikawa, 1969, 1976) to discover and eliminate (symptomatic solution) but as the undesired effects of the functioning of some system – or subsystem – that must be recognized, specified and controlled (definitive solution).

From this general rule, some specific principles can be derived:

**First principle:** apply Systems Thinking above all to avoid problems from arising or appearing too soon, when the symptom is not yet high.

Systems Thinking helps us with a second very relevant principle:

**Second principle:** the symptoms are not the problem but a sign that some problem has caused them. Do not stop at the symptom but apply Systems Thinking to recognize the true nature of the problem and avoid symptomatic solutions which, by not solving the problem but only eliminating the symptoms, often aggravate it.

**Corollary:** try to determine if, by your behavior, you “are part of” the problem or “the problem itself”.

Albert Einstein reputedly said, “If I had an hour to save the world, I would spend 59 minutes defining the problem and one minute finding solutions.” Unfortunately, most organizations are running around spending 60 minutes finding solutions to problems that do not matter. […] One of the greatest skills an organization can possess is the ability to ask the right question in the right way (Shapiro, 2011, online).

The pressing outbreak of a symptom – perhaps as the consequence of inefficient problem solving – requires us to understand the system from which it has originated (Figure 7). We know that systems structures are found in various contexts and produce similar effects. Knowledge of the system structure is indispensable to avoid activating processes that could produce undesirable effects. In particular, we must pay attention to the creation of reinforcing loops which, if triggered, would lead to devastating effects. We can therefore formulate these additional principles:

**Third principle:** in problem-solving, it is necessary to always consider the decision in the context of some systems process – which characterizes a given situation of an individual or organization – whose network of processes must be specified through the construction of a meaningful Causal Loop Diagram. The symptom is not “the” problem, because “the” problem lies in the structure of the system and its dynamics (Figure 7).

**Fourth principle:**

- In finding solutions for systemic problems, do not be content with symptomatic solutions; look for systemic-structural levers that can produce the more incisive effect.
- If there are several systemic levers, choose the most efficient and effective one, which produces the maximum effects with the minimum effort.
- The choice of structural and decisional levers, as well as the intensity of the actions to modify their values, must follow from a careful construction, interpretation and assessment of the system’s causal map.

Peter Senge defines a definitive solution that exploits the potential of the system’s structure and its loops – not limiting itself to symptomatic interventions on individual variables – as the leverage effect.
The advantage of systems thinking derives from the leverage effect – seeing in what way the actions and changes in the structures can lead to long-lasting, meaningful improvements (Senge, 1990/2006, p. 131).

We can derive the:

**Fifth principle**: if you want to solve a problem by modifying the system structure or by introducing new programs that readjust the processes, then always remember the law of dynamic instability (Section 4) and pay attention to:

- the changes that can trigger dynamics of expansion or reduction. No expansion or reduction will be maintained for long; each reinforcing loop always produces a balancing loop that, in the long run, can also reverse the direction of the dynamics; and
- the changes that balance dynamics of expansion or reduction; every balancing loop generates contrasting processes that can prevail and restore the original dynamics, often in the reverse direction.

This last principle represents the logical conclusion to the application of the first principle:

**Sixth principle**: try not to commit the same mistake two (or more) times; if today’s problems come from yesterday’s “solutions” (Senge, 1990/2006, p. 57), you must ensure that today’s solutions, no matter how capable they are of solving the problem, do not create new problems tomorrow.

Although these rules are clear and acceptable, the problem-solving process is not easy; the large number of variables, the different levels of influence, and the time dynamics represent problems in applying Systems Thinking to problem-solving. A careful inspection of the structural map of the system that generates problems should normally allow us to identify definitive solutions. Often, however, the errors are so subtle that they are not perceived, and thus they become almost inevitable. In fact, the CLDs do not automatically highlight any solution;
instead, they must be carefully studied to identify one or more linked loops – which are called system, or structural levers – which, by being acted upon, can cause the leverage effect. This represents the most difficult moment; if we cannot recognize the system lever that can bring about the leverage effect, then no decision can be said to be consciously taken and no problem definitively resolved.

7. Senge’s list of system archetypes: Senge’s list can be enlarged
In any type of organization, we can identify standard structures known as systemic archetypes. These are general models of relations that frequently recur in various situations and in different environments whose aim is to rapidly increase the capacity of the decision-maker/manager to perceive the systemic problems and recognize the structures that determine these problems, for the purpose of formulating definitive solutions and avoiding (re)producing erroneous, ineffective solutions that can give rise to the same problems, as well as to new ones.

One of the most important, and potentially most empowering, insights to come from the young field of systems thinking is that certain patterns of structure recur again and again. These “systems archetypes” or “generic structures” embody the key to learning to see structures in our personal and organizational lives […] Because they are subtle, when the archetypes arise in a family, an ecosystem, a news story, or a corporation, you often don’t see them so much as feel them. Sometimes they produce a sense of déjà vu, a hunch that you’ve seen this pattern of forces before. “There it is again,” you say to yourself (Senge, 1990/2006, p. 93).

The archetypes can be used as templates for diagnosing vexing long-term problems (Kim, 2000, p. 2).

The systems archetypes – of which there are only a relatively small number – suggest that not all management problems are unique, something that experienced managers know intuitively. If reinforcing and balancing feedback and delays are like the nouns and verbs of systems thinking, then the systems archetypes are analogous to basic sentences or simple stories that get retold again and again (Senge, 1990/2006, p. 81).

In his book (in particular, Appendix 2), Peter Senge presented 10 archetypes which, in his “original list”, are:
(1) balancing process with delay;
(2) limits to growth (also known as Limits to Success);
(3) shifting the burden;
(4) special case: shifting the burden to the intervenor;
(5) eroding goals (also known as Drifting Goals);
(6) escalation;
(7) success to the successful (also known as Path Dependence);
(8) tragedy of the commons (Hardin, 1968; Ostrom, 1990);
(9) fixes that fail; and
(10) growth and underinvestment.

The literature on Systems Thinking, along with many consultants, have normally considered Senge’s archetypes as a finite set (e.g. Wolstenholme and Corben, 1993; Dowling et al., 1995; Kim, 2000; Kim and Anderson, 2011, Braun, 2002; Heaven and Earth Incorporated, 2000; Continuous Improvement Associates, 2003; Bellinger, 2004; Dempsey, 2015; Insight-Maker, 2017), even if other authors had presented their own list of system archetypes that could be applied in specific contexts, for example, Forrester (1970) and Meadows (1982).
Nevertheless, Senge’s list represents the most frequent and visible archetypes in organizations, even though it can be extended. Above all, most of Senge’s archetypes present a mirror-image archetype, to which new important and significant archetypes can be added. Considerations of space make it impossible to present these in detail. Instead, the most interesting ones will be briefly described, in addition to the most relevant in Senge’s list, leaving the reader to refer to the present author’s writings (Mella, 2012, Ch. 4; Mella, 2014, Ch. 5) for a more in-depth treatment with examples.

Archetype of the:

- **Fixes that fail**: urgent and short-term problem-solving strategies can be adopted in dealing with certain problems which nevertheless cause unforeseen consequences – which will appear later – that make continual readjustments of the solution necessary (Senge).

- **Shifting the burden**: when a symptom arises, symptomatic solutions can delay the search for the problem and the adoption of definitive solutions; such a delay can lead to collateral effects which further impede the search for long-term solutions. Systems Thinking favors and accelerates the search for a definitive solution (Senge).

- **Eroding goals**: the manager/decision-maker, perceiving the difficulties in achieving the objective (symptoms), often responds by “adjusting” the objective – that is, by reducing the system’s performance expectations – rather than intervening on the operational conditions that give rise to the problem itself (Senge).

- **Strengthening goals or insatiability**: when the manager/decision-maker obtains a result above the standard, instead of reducing the action to achieve the objective he continually raises the level of the standards (mirror image archetype).

- **Degradation of the error assessment**: an altered perception of the “distance” from the objective induces the decision-maker to undersize the decisional lever, thereby producing a new deviation (mirror image archetype).

- **Persistence**: the wrong perception of the deviation induces the decision-maker to overestimate the error and to activate every possible lever to eliminate it, showing by such intolerance toward any slight deviation a true persistence, or even implacability, in the control action (mirror image archetype).

- **Success to the successful**: there is a tendency to assign more resources to those who successfully use them. The subject that receives more resources has a greater probability of a better performance compared to subjects whose performance remains stable over time. Thus, an initial distribution of resources produces a permanent performance differential (Senge).

- **Punishment for success**: The person who works better is always given more work; the shirkers are instead very often underutilized. It almost seems as if the successful person, the one with the better performance, is punished by being given more to do (mirror image archetype).

- **Tragedy of the commons**: when two or more subjects share a common resource, sooner or later it will be depleted. “Freedom in a commons brings ruin to all” (Hardin, 1968, p. 1244) (Senge).

- **Limits to growth**: nothing grows *ad infinitum*. Every growth process that entails a growth condition available in limited quantities is destined sooner or later to end (Senge).

- **Growth and underinvestment**: when growth is slowed by the gradual saturation of the productive capacity, and this saturation could, in turn, be eliminated through
additional investment in capacity, normally the capacity saturation impedes new investment as well (Senge).

- **Accidental adversaries**: when two or more subjects cooperate for their mutual success, parallel to or subsequent to actions to collaborate and support one another to achieve such success they also act to pursue their own personal and individual success, continually impeding one another and lowering the collective and individual performance (Senge).

- **Short-term, individual and local preference**: preference for short-term, individual or local advantages hide the collective and global disadvantages that will occur over the long term; for this reason, short-term, individual and local advantages are preferred to long-term and global disadvantages (*new archetype*).

The simple structure of the last archetype is shown in Figure 8, from which we can draw this conclusion: repetitive behavior produces short-term advantages (vertical arrow “s”), which, in turn, encourages the continuation of the behavior, according to loop \([R^1]\). The current advantages reduce the perception of the long-term disadvantages – which are thus produced with a considerable delay – and this encourages even more of the same behavior to gain present advantages, as shown in loop \([R^2]\). The two loops act together to increase short-term preferences, which guide behavior and inexorably create long-term problems when the disadvantages caused by the repeated behavior appear, so that the long-term disadvantages do not condition behavior but represent only its effect (no loop).

There is no way out: this archetype is always in action, and when it is not it is always lurking. Therefore, if we wish to avoid the harmful consequences of the actions of the three archetypes, it is necessary to act to counter the reinforcing effect of loops \([R^1]\) and \([R^2]\), as shown in Figure 9.

The third form of intervention to reduce the negative effects from the action of the archetype is to act directly on the agent’s current behavior through incentives or
8. Conclusion: do managers require Systems Thinking to improve their intelligence?

In his book, Peter Senge indicates to managers the “superiority” of Systems Thinking not to propose a new form of thinking about systems but to emphasize the need for managers to think systematically in their daily tasks (Best and Holmes, 2010) of observing (understanding), judging (deciding) and solving problems (controlling):

We understand that the only competitive advantage the company of the future will have is its managers’ ability to learn faster than their competitors. So the companies that succeed will be those that continually nudge their managers towards revising their views of the world. The challenges for the planner are considerable (de Geus, 1988, p. 72).

Precisely for this reason, Senge considers Systems Thinking not as a technique but as a discipline – the Fifth Discipline – in accordance with the framework that we have indicated in Section 2:

This discipline helps us see how to change systems more effectively, and to act more in tune with the larger processes of the natural and economic world (Senge et al., 1994, p. 6).

A discipline is a developmental path for acquiring certain skills or competencies. […] To practice a discipline is to be a lifelong learner. You “never arrive”; you spend your life mastering disciplines (Senge, 1990/2006, p. 10).
The conceptual framework adopted in this paper can be summarized in three points:

1. Intelligence is the ability to develop a system of coherent and meaningful models that allow us not only to survive in a world that is continually evolving but also to improve ourselves and make progress.

2. The most powerful and effective models are the systems ones that view reality as a set of connected and dynamic variables forming a whole. An understanding of the connection between the parts and the whole and their dynamics is the fundamental characteristic of operational and creative intelligence.

3. The most interesting and useful connections among the elements that make up reality are not the linear ones – characterized by chains of causes and effects – but the circular ones, the feedbacks and loops, which make the elements not only connected but also interconnected, not only dynamic but also interactive. The only efficient thinking is Systems Thinking.

By adopting Senge’s view of Systems Thinking, four basic topics have been developed, which represent the core objectives of this paper:

1. First is to transform the conceptual “framework” into an operational instrument by indicating a “language” that makes it easy to construct CLDs.

2. Second is to present the logic of Control Systems, which normally are multi-levered and multi-objective and, to be operationalized, require two “figures/functions”: management, which formulates the strategies that specify the control levers and the extent of their activation, and the governance, which defines the policies, that is, the priorities among the objectives and the minimum and maximum degree of their achievement. We have observed above that often it is not possible to control the individual variables that interact with others because the loops can thwart the control process and move the system toward its initial state.

3. Third is to reflect on the problem-solving process by pointing out how problem solving can be equated to a Control System. The present paper presents a set of 6 principles that can aid management in making the correct decisions. In particular, we have noted that the intelligent manager must understand that problems do not arise from the anomalous dynamics of some variable – which represent the symptoms of the problem – but from the systems that produce these dynamics. Knowledge of the structure of the systems that produce the problems, which is acquired by representing them with appropriate CLDs, is thus fundamental to improving intelligence in managers.

4. Fourth is to emphasize the importance of systems archetypes as diagnostic models that identify the “systems sources” of problems and the possible control strategies. Since the archetypes are instruments of intelligence, our paper proposes some additions to Senge’s list of archetypes.

The paper contributes to the literature by highlighting how the aforementioned topics – systems models and CLDs, Control Systems, decision-making, and systems archetypes – are connected to form, as a whole, a powerful intelligence tool, since they allow the manager to quickly structure the models of knowledge needed to effectively carrying out his work. In fact, Systems Thinking, through the logic of Control Systems, offers managers a comprehensive and exhaustive representation of the problem solving and decision-making processes, teaching them how to recognize problems and not only symptoms and to acquire a leverage effect. By identifying the system archetypes, Systems Thinking enables managers
to quickly recognize the fundamental system structures that can create problems for their organization, suggesting the action levers that can bring the problematic structure under control (Checkland, 1999, 2000).

In short, the Systems Thinking discipline is therefore a fundamental tool for developing managers’ intelligence and, more in general, our intelligence, because of the following:

- Managers are required to specify the point of view of their observations; every phenomenon is an input or output of a system according to the point of observation.
- Managers are obliged to consider the circular relations among phenomena and the interconnections between processes and systemic structures; and by verifying the existence of other interconnections, it does not limit managers to considering only the immediate interdependencies.
- Managers are forced to consider their own actions as elements in a system of interdependent decisions. This discipline teaches managers that their behavior depends on the entire state of the systems of which they are a part; a state that, however, is modified precisely because of their own actions, thereby initiating the process of learning from experience.
- Managers are obliged to reflect on the causes of their behavior, making them aware that the effects of today’s actions can be a motivation for tomorrow’s actions, and that they are not only spectators but also actors in the systems that make up their world; managers must feel responsible for the system’s performance (Drucker, 1986).

As by nature, Systems Thinking considers systems as dynamic, it is “natural” to develop simulation techniques that numerically and graphically represent the succession of values generated by the system under examination (Richmond, 1994; Sterman, 2001). Systems Thinking, when quantitatively expressed in simulations, is commonly known as the study of the dynamics of dynamic systems, or System Dynamics, a discipline that goes back to Jay Forrester and his fundamental book Industrial Dynamics (Forrester, 1961). In a recent article, the founder of this discipline defines it in this way:

System dynamics involves interpreting real life systems into computer simulation models that allow one to see how the structure and decision-making policies in a system create its behaviour (Forrester, 1999: p. 1).

System dynamics provides a common foundation that can be applied wherever we want to understand and influence how things change through time. [. . .] System dynamics uses concepts drawn from the field of feedback control to organize available information into computer simulation models (Forrester, 1991, p. 5).

Among the many possible simulations are those that allow us to create true “microworlds” from which managers can reproduce the observed dynamics, carry out simulations to identify and solve problems and program the “future” of the system by controlling the evolution of the variables.

Simulations are not tools to predict the future. Rather, they are virtual worlds or microworlds in which managers can develop decision-making skills, conduct experiments, and play (Sterman, 2001, p. 21).

[. . .] microworlds “compress time and space” so that it becomes possible to experiment and to learn when the consequences of our decisions are in the future and in distant parts of the organization (Senge, 1990/2006, p. 313).

As the paper seeks to present several useful aspects of the Systems Thinking discipline, the simulation models have not been analyzed in detail, also because of limits imposed by the
length of the paper. Partly for this reason, it does not include practical examples; however, this limit can be overcome by referring to the literature cited below.

Of course, some managers will not be content only with Systems Thinking models, but for those with little time or resources to construct more sophisticated (though less immediate) models, the following proverb always applies: *Beati monoculi in terra coecorum*; that is, in a dynamic and complex world, blessed are those who, knowing how to construct Systems Thinking models, have at least one eye in a land of blind people (Mella, 2012, p. 8).

### References


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Mechanisms of meme propagation in the mediasphere: a system dynamics model

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Abstract
Purpose – In the age of internet memes spread around the world in very short time, it has been already proved that, in several cases, the mechanism of propagation is very similar to a flu infection. However, this model turns out to be invalid if the spreading is generated by the mass media (TV, radio and the like). This paper aims to explore for the first time this non-viral dynamic (“fallout model”).

Design/methodology/approach – Two different dynamic models were developed to explain the viral and the mass media-powered meme propagations, and both were tested using data from Google Trends.

Findings – Viral propagation is not the only mechanism of meme diffusion. Memes can also diffuse by a “fallout” model, in which the susceptible populations are affected by the meme messages almost simultaneously, as it happens in the physical world for a radioactive fallout or for other poisoning agents.

Originality/value – This study provides a method to determine whether a certain meme has been diffusing by means of its own viral power or has been “planted” as the result of a commercial advertising campaign or a government propaganda operation.

Keywords System dynamics, Google Trends, Mass media, Meme, Viral replication

Paper type Research paper

Introduction
The term meme was coined in 1976 in Dawkins’ book The Selfish Gene (Dawkins, 1976), where it was defined as any cultural entity that exhibits self-replication. The word origins from biology: just as biological genes replicate themselves using individual creatures as hosts, memes replicate themselves using human brains as hosts.

Today, the internet represents the preferential medium of meme diffusion: blogs, forums, image boards such as 4chan, social media and more are the main mechanisms that propagate memes around the world (Schubert, 2003). For this reason, in the recent years, the number of studies on this theme increased exponentially. Just think about the work of He et al. (2016), in which a powerful scheme for the meme ranking was elaborated using data from both American and Chinese blogging systems. This work also provides an in-depth literature review on the main meme diffusion models (cascade models, epidemic models and competitive models), we refer to for further information and details, without reproducing the same work in the present paper. Ross and Rivers (2017) study assesses that ad hoc created memes show all their power in to delegitimate the figures of the candidates Hillary Clinton and Donald Trump during the last campaign for US presidency. This example of memes related to politic events is the demonstration that, in a digital culture, any individual with a basic digital equipment can find in the creation of a meme a form of social participation that might not have before.

Moreover, a meme is not only an entity that spreads across the Web, it can also be recognized as a new form of knowledge unit, transmittable between individuals, as reported
in detail in the investigation from Beck-Fernandez and collaborators (Beck-Fernandez et al., 2017).

Anyway, in all the previously cited studies, the meme is generated and tracked in the Web: forum, blogs and meme creators are all hosted on the internet. But memes can be also originated by other media, in particular, the traditional ones, like TV and radios, which have the possibility to spread information worldwide almost at once.

In the present study, for the first time, we discuss and compare the birth of a meme and its dynamic propagation both on the internet and in mass media environments. To grasp this fundamental difference in the meme's origin, we built simple and intuitive models, with the system dynamic (SD) methods. SD models are particularly useful in representing the structure of complex systems, especially the non-linear systems, in which the properties-of-the-whole system are different from the properties that characterize the system's constituent elements so that the behaviour of the whole cannot be explained in terms of a combination of the behaviour of the single parts.

The result of our study reveals that the origin of a meme can be due to two different activities: internet propagation or media bombardment.

Methodology
To explore the propagation of memes in the mass media environment, we started by taking into account the recent work by Wang and Wood (2011). Wang and Wood used the SIR (sane–infected–recovery) contagion model, constituted by a non-linear system of three differential equations, to fitting meme propagation data found in Google Trends. The SIR model describes one of the most frequent dynamics recognized in meme spreading (Kubo et al., 2007) (Kermack and McKendrick, 1927), even before the internet era, so that it might be reasonable to test it also to identify meme origin not strictly connected to the Web.

To represent the Wang and Wood mathematical dynamic model may become more intuitive if we translate the SIR system of differential equations into SD modelling (Pruyt, 2013). With SD tools, differential equations can be translated into graphical objects: stocks (the variables) and flows (their derivative to time). In this way, the description of the SIR dynamic can be represented with a scheme constituted by three stocks and two flows. The S, I, R populations are assimilated to stocks, whose sizes depend on the rate with which individuals pass from to be sane, in infected and finally in recovered.

In the present study, we use the “Vensim™” software tool, developed by Ventana Systems. With this tool, the stocks are graphically represented as boxes, whereas arrows represent the flows in and out of the stocks.

To fit Google Trends data, we used discrete formulas for the differential equations to write a code in Excel, with which we calculated optimized equation parameters using the least-squares method (parameter solver function of Excel). After fitting, the goodness of fit (GOF) is provided by the Matlab function “GoodnessofFit”, with the normalized minimum sum of squared errors (0 = bad fit, 1 = ideal fit).

As already mentioned, all our models take into account three stocks of the population (or of “agents”): susceptible, infected and recovered.

“Susceptible” defines people who have not yet come in contact with a particular meme. “Infected” refers to those agents who are under the influence of the meme, and they are supposed to take an active interest in the idea, for instance searching for it on the Web. “Recovered” represents the stock of people who have lost interest in the meme and are not anymore actively searching for it or diffusing it.
We suppose that:

\[ \frac{dS}{dt} + \frac{dI}{dt} + \frac{dR}{dt} = 0 \]

which means that the population size is constant, at least in the lapse of time the infection is taking place. This allows reducing the system of differential equations from three equations in three variables (S, I, R) to a system of two equations and two variables (S, I). Moreover, no re-infection dynamic is proposed, assuming that the probability of being re-infected by the same meme is very low. The graphical representation of the classic SIR model is shown in Figure 1.

The same model can be expressed in terms of two differential equations:

\[ \frac{dS}{dt} = -k_1SI \]

\[ \frac{dI}{dt} = k_1SI - k_2I \]

Where \( k_1 \) is the “transmission rate” proportionality constant. It represents the fraction of interactions that result in a susceptible individual becoming infected with a meme. \( k_2 (\leq k_1) \) is the “recovery rate” proportionality constant. It controls the rate at which individuals infected are recovered and develop immunity, avoiding reinfection. We consider here that the recovered agents lost interest in the meme because they have memories of it, at least for the same lapse of time considered to assume a constant population of susceptible. The curve of “infected” according to the previous dynamic is shown in Figure 2.

We tested this model with several data, again from Google Trends, and we found that some of them perfectly matched the SIR dynamic, but there were also others set that at first glance looked to describe curves very similar to the ones produced by SIR, but, actually, they were not fit by that model. For this reason, we hypothesized the existence of another meme’s dynamic, resulting from the spreading on the mainstream mass media sources as journals, TV, Web channels and others. In this model, we called “fallout” propagation, the infection does not start from a single point and propagates across the same agents by means of dual interactions, but it has planted on a large number of susceptible receptors, thanks to the simultaneous action of mass media. To maintain the disease metaphor, a meme going viral is the equivalent of the flu epidemics propagation, whereas a meme diffused by the
mainstream media is the equivalent of the effect caused by a poisonous or radioactive cloud. This phenomenon is represented by the dynamic model shown in Figure 3. The only difference in comparison with the SIR model is the lack of the infection feedback.

In this case, the equations are:

\[
\begin{align*}
\frac{dS}{dt} &= -k_1 S \\
\frac{dI}{dt} &= k_1 SI - k_2 I
\end{align*}
\]

In this case, the meme spreading is described by a curve where the number of people infected increases rapidly, without showing an inflection point, as it is instead observed for viral diffusion. The decline instead is similar and, indeed, it is described by the same mechanism.

Figure 2.
Infected population evolution with time under a viral mechanism

Figure 3.
Stocks and flows representation of the modified SIR model according to the system dynamics method (media bombardment)
The equations $dS/dI = -k_1SI$ and $dS/dI = -k_3S$ obtained from the two models, respectively, are used to fit data taken from “Google Trends”.

The meme distributions, fit using the first equation, have been supposed following the “natural” interest of the public, whereas those curves fit with $dS/dI = -k_3S$ are hypothesized diffusing as a fallout, induced mainly by mass media, as explained by the second model.

**Results**

Memes are often said to diffuse by “going viral”, which implies pairwise interactions between agents acting as nodes of the network – this is a mechanism that has been observed to take place on the Web. We confirmed these results using data taken from “Google Trends”. There are several examples where the ramping up of the induction time of the spreading of the meme can be clearly observed. In Figures 4-6, we show this behaviour for three well-known terms: “Gangnam”, “Facebook” and “Android”.

In Figure 5, we show the data and the fit for the term “Gangnam”. Gangnam is a district of Seoul, but it is also the title of a song by a Korean rapper that went strongly viral in 2012-2013, *Gangnam Style*. Note how the “viral” characteristic of the infection is shown by the induction time at the beginning, and note the accuracy with which the data are fitted by our simple viral model: the GOF is 0.95. These data tell us that the “Gangnam” infection was a true viral infection that spread from site to site, from agent to agent, without being promoted by the mass media, at least at the beginning. Indeed, *Gangnam Style* broke YouTube records with 1 billion hits on 21 December 2012, and this news was broadcasted by the mass media, which picked up the story ([www.dailymail.co.uk/tvshowbiz/article-2251809/Gangnam-Style-breaks-YouTube-record-1-BILLION-hits.html](http://www.dailymail.co.uk/tvshowbiz/article-2251809/Gangnam-Style-breaks-YouTube-record-1-BILLION-hits.html)), provoking a new wave of “clicking”, as seen by the spike in the Google Trends data for late 2012.

Also, for social network words, as “Facebook” or “Twitter”, that have penetrated our daily life more silently, but constantly, we can observe a broader bell-shaped curve. This is a typical example of propagation by means massive social interactions, the same mechanism of the flu. In Figure 6, we report the term “Facebook” fitted with the viral model, and also, in this case, the GOF is very good, around 0.95.
As a further example, we report the case of the OS “Android” (Figure 7), which in few years has become the most diffused OS for smart devices. Today, the infection is “recovering” owing to the fact that the meaning of this term is now uniquely acquired in the common language. The GOF is 0.98.

Google Trends can also provide examples of “fallout” spreading where the mass media broadcasting power plays the major role. A good example of this is the term “Cecil the Lion”, which refers to the episode of the death of the Zimbabwe National Park mascot lion that was killed by suspected poachers in July 2015. The report of the death of Cecil generated a considerable uproar on the Web and, in terms of frequency of clicks, the
result is a sharp peak without any detectable inflection point at the origin of the peak. The fitting of the data confirms what is known about this episode: it was diffused mainly by the media. The data of Google Trends and their fitting with the fallout model are shown in Figure 8 (GOF 0.77).

Several unexpected events show this behaviour, and when they happen, they are promptly spread by the media. Two more examples of fallout dynamics are shown in Figures 8 and 9.

One is the term “Bataclan”, the location of the terrorist attack in Paris on November 2015, and the other term is “Amatrice”, the name of the Italian village that was destroyed after the
earthquake in August 2016. Both terms show a very similar sharp peak; we report here only the one related to the word “Bataclan”.

Not only tragic events show a fallout dynamic. This is the case of the term “Tesla” (Figure 10). It is well known that this term indicates the unit of magnetic induction, the name of the scientist Nikola Tesla and, only recently, the name of a brand of electric cars.

In particular, we can assess with our fallout model that the bump showed in Figure 10 coincides with the announcement made by the Tesla company, at the end of March 2017, about the release of the Tesla “Model 3”. The peak that overhangs the baseload search

Figure 9. “Bataclan” term propagation under a fallout propagation

Figure 10. “Tesla” term propagation under a fallout propagation
frequency of such a term is in correspondence with the announcement by the mass media of this new model, and we can see that there is no inflection at the base of the peak and that it can be accurately modelled with the fallout dynamic.

It is also possible to find examples of mixed viral/fallout propagation behaviour. For instance, the launch of new products on the market is announced by the mass media, thus is supposed to follow a fallout mechanism, but we can not exclude the news might propagate by the means of social interaction too. In Figure 10, we report the results of the terms “Apple” and “iPhone”. Whereas the term “Apple” is commonly intended as the fruit and has an almost flat historical trend, if it is paired with the term “iPhone”, we can observe that, never before the launch of the first “iPhone”, in June 2007, those two words were searched together, obviously because the term “iPhone” did not exist yet and was not associated with the “Apple” company.

Then, in 2007, something changed, those two words start to be correlated, and this is owing to the fact that the Apple company launched the new product on the market by a mass media intervention. In Figure 10, we can see that the peak repeats every time that the homemakers announced a new version of the product and that the propagation of this new product has also a viral background on which advertising dynamics are planted.

Something very similar happens also to new ideas. In Figure 11, we report another case of mixed behaviour, the case of the “E-cat”, an energy device pretended to produce energy with an innovative catalyst. It is possible to note how the initial diffusion of the concept was viral, implicating the probable use of “search engine optimization” methods by the inventor. At a later moment, the mass media took over and we observe a sharp increase of clicking. Notice also the several successive bumps that correspond to successive press releases by the inventor. They were scarcely effective, as the public had developed a certain resistance to the infection (Figure 12).

Discussion
Thanks to the data analysed in the previous paragraphs, for the first time, we used SD to show that viral infection is not the only diffusion mechanism for meme propagation in the

Figure 11. “iPhone” term as an example of a mixed viral/fallout propagation behaviour.
Another mechanism may take place especially if the meme is generated outside the Web, as in the case of mass media propagation. We called this mechanism “fallout”, as it spreads in the same way as a nuclear fallout cloud. We recognized and defined that these two mechanisms have a different origin. In particular, the pure fallout mechanism is the result of an external entity that purposefully spreads the meme in a scattershot burst that reaches multiple active agents at the same time.

Discriminating between these two different mechanisms has an interest in terms of understanding the origin of specific memes and their possible purposes. For example, when the earthquake of Amatrice occurred, immediately the news was broadcasted by TV and radios around the world with the aim to inform people about the impact of the disaster, such that also the Web searching of news related to this event increased almost instantaneously. A very similar behaviour is observed also when the Tesla company launched the new model of electric cars on the market; in this case, the advertising by the mass media was mainly oriented to induce people to purchase the product. The “fallout” mechanism in advertising is also particularly evident for the “iPhone” products. Every time a new exemplary has announced on the market, the searching peak frequency of that term comes out sharply over the average frequency in the rest of the periods.

Thus, the aims of our models are to furnish a tool to understand if a meme diffuses virally or if the propagation is amplified from a radiative spreading, something that is simultaneous in all the directions. We propose a way to distinguish these two mechanisms to analyse, for example, marketing dynamics. This approach is also validated by the use of data from Google Trends, which has been already recognized as a very useful database to interpret “collective behaviour”, aggregate demand (Choi and Varian, 2012), stock market moves (Siganos, 2013), investor expectations (Vlastakis and Markellos, 2012; Da et al., 2011; Drake et al., 2012), information demand (Vosen and Schmidt, 2011), attention or market sentiment (Carriere-Swallow and Labbè, 2013; Preis et al., 2013). The normalized frequency of search allows to compare the interest in a determined term anonymously it represents a sort of gauging of collective mindshare and awareness, and this is why even though we examined different terms from different areas of interest, the data fitting is extremely accurate.

We recognized that this level of aggregations is not probably informative enough for operational policy analysis and design; also, because operational policy that wants to go beyond a global perspective must take into account regional conditions.

Figure 12.
“E-Cat” term as an example of a mixed viral/fallout propagation behaviour.
Anyway, owing to the simplicity of formulation, we think that our models could be also used to test collective behaviour at sub-geographical levels, so the results will be more sensitive to the reality of that specific region. This topic will be objective of future studies.

**Conclusion**

The concept of “meme” in communication is based on that of “gene” in biology. However, the correspondence is not exact, and memes have characteristics that genes do not have. In particular, memes can be “planted” in the mediasphere using a top-down mechanism based on scattershot diffusion on the part of the mass media. This behaviour can be seen as parallel to that of the radioactive cloud generated by a nuclear incident. The distinction between these two mechanisms can be useful to understand whether a specific meme is the result of a “natural” interest of the public that derives from its special virtues or has been diffused as a top-down operation designed to influence the public or the consumers of a specific product.

**References**


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Smart technologies as social innovation and complex social issues of the Z generation

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Abstract

Purpose – This paper aims to present how contemporary students are self-organizing using smart technologies (ST) and the future social implications of ST. The research model is based on the concepts of the soft system methodology, social systems thinking, innovative smart systems, and cybernetic and knowledge management.

Design/methodology/approach – The study contains elements of exploratory and descriptive case studies. Narrative analysis and interpretation of the collected data have been carried out.

Findings – Students mostly use ST to save time when studying and in their free time. Students are surprised by how ST developed and are cautious when imagining how the technology will change and affect their lives. They are concerned regarding several ethical dilemmas of using it, such as privacy and spending time with their loved ones and friends. Students perceive their self-organization in the future as very dependent on the availability of ST in institutional settings (e.g. education and business process) as well as their personal lives. Students discuss their present perceptions about what the future will be and note that social system will be more dynamic in terms of socialization, and loss of personal contact with their friends and family is seen as the main threat.

Research limitations/implications – The research is qualitative, and the questionnaire was carried out among business students at the Faculty of Economics, University of Ljubljana, Slovenia.

Practical implications – The paper offers an understanding of the usage of ST among business students. This study provides a road map of a few possible ways for usage of ST among students. The topic is also relevant for human resource managers, technology developers and marketing strategists for their better understanding of the behaviour of young people using ST in professional or private environments.

Social implications – The findings can be useful for professors in identifying different learning methods that are useful for their students.

Originality/value – The authors offer conceptualizations of ST within the social innovation framework and provide a contemporary understanding young people’s ST usage.

Keywords Behaviour, Qualitative research, Knowledge management, Collective intelligence, Innovative smart systems, Z generation

Paper type Research paper

1. Introduction

Evolving technology has caused young generations to be increasingly exposed to constant social and technological changes in the environment, which consequently requires new skills and investment in attaining, sharing and creating knowledge, which requires access to
information systems and, consequently, networking (Lu et al., 2016; Sharma et al., 2016). Generation Z (also called iGen) is the first generation that has never experienced life before the internet; members of this generation are defined as digital natives in the literature (Akçayır et al., 2016; Bennett et al., 2008; Wang et al., 2014). Turner’s (2015) opinion was that Generation Z is the first to have lived in a time that technology is so accessible to a young people. The affordability of technology (e.g. smart phones, tablets, Internet of Things and smart TV) to wider segments of the population has enabled Generation Z (and especially Generation Alpha [born after 2013]) to become constantly engaged in communication in an online world (Issa and Isaias, 2016; Rickes, 2016; Turner, 2015). The significance of the smartphone in their lives is shown in a 2017 survey of more than 5,000 American teens, which found that three out of four owned an iPhone (Twenge, 2017). In the previous decade, the smartphone (Apple’s iPhone was launched in 2007, when the oldest members of Generation Z were adolescents) has radically influenced the nature of this generation’s lives (from social interactions and work habits to their mental health) (Berger, 2017; Carbonell et al., 2018; Kouloupos and Keldsen, 2016; Lee et al., 2017; Rosen, 2010).

Business students perceive smart technologies (ST) to be a tool for knowledge acquisition and sharing in their private, academic and future professional lives. ST enables new solutions for social problems by identifying and delivering new services that improve the quality of life of individuals, identify and implement new labour market integration processes, new competencies, new jobs and new forms of participation, that contribute to improving the position of individuals in the education and work setting, which is in line with the conceptualization of social innovation by Murray et al. (2010).

The purpose of this paper is to present the perceptions of business students about their ST usage. Previous research (Lambrechts and Sinha, 2016) established that ST depends on socio-demographic factors; therefore, we focused our research on business students (members of Generation Z) and their in-depth perceptions of ST now and for the future.

The study, carried out among business students at the Faculty of Economics, University of Ljubljana, Slovenia, provides the views of 144 young people on the use of ST and their opinions about the impact of emerging ST on new forms of communication, acquisition and dissemination of information now and in the next 20 years.

Qualitative analysis generated answers based on content analysis to the following questions:

Q1. How do students use ST to consume, create and share content now and how do they envision using them in the future (e.g. in the next 20 years)?

Q2. How will ST influence respondents’ private and professional communication and, consequently, the quality of their lives in the next 20 years?

Q3. Among the proposed factors (personal and contextual factors, opinions of emerging (smart) technologies and self-regulation behaviours), which most influence students’ use of emerging ST to consume, create and share content accordance of their ST habits in their private and professional lives?

The study was designed according to the general method of case studies (Easterby-Smith et al., 2005). A study on the impact of ST in the future life processes contained elements of exploratory and descriptive case studies. According to Dimovski et al. (2008) and Yin (2005), a combination of both grounded theory and case study are appropriate for the design study model, which enables using the researched results in practice. Narrative analysis and interpretation of the collected data has been carried out (Roblek, 2009).
The structure of the paper is as follows: in the first part, we provide the theoretical background of the ST; in the second part, we state the methodology used; and in the third part, we elaborate on the empirical results and further implications.

2. Theoretical background

2.1 The growth of smart technologies

In the first decades of the twenty-first century, society was confronted with the increasing influence of the internet and ST on basic human functioning; these technologies have caused organizational and social changes. Full automation, artificial intelligence systems and digitalization have become pervasive in manufacturing, services and in people’s private lives. Smart connected technologies that include sensors and cameras are a part of new vehicles, homes, kitchen appliances, etc. (Sommer, 2015).

These rapid developments in recent years have raised the question of the impact of changes on human life. To find solutions for consequences of ST, it is necessary to analyse the impact of these technologies on future human interactions. Attention must be paid to the systemic complexity of the possible problems to which people are exposed.

What the phenomenon of ST actually represents is that emerging technologies will influence private and professional communication, and consequently, the quality of human life and the development of collective networks based on strategic intelligence in which parts of the economy and the human environment it is expanding is probably most evident from the expressions with which it is associated (Castells, 2010; Nitti et al., 2015; Starlard-Davenport et al., 2016; Odella, 2016). ST have become an indispensable part of Generation Z’s lifestyle. They are growing up with technologies, and online social networking services have become one of their most important communication channels. One theory is that with Generation Z, we cannot talk about the technological addiction because the technology is inseparable part of their lives (Turner, 2015).

2.2 Importance of smart technologies for social relations among young people

Members of the social system (in this, students as users of ST) vary considerably according to the speed of accepting innovation. Research (Carro et al., 2014; Hunt et al., 2015; Rauschnabel et al., 2015) has shown that young people are significant ST adopters. Young consumers in TICKS (Taiwan, India, China, South Korea) countries are adapting to technological changes, such as e-commerce and online shopping, much faster than in the USA, and their adaptation of the technology is changing the nature of the emerging markets (Johnson, 2016). Young people are major participants in the development and use of open innovations, which influences the transformation of the customer-oriented perspective into the community-oriented ones “which include social capital of the community” (Petrau and Daskalopoulou, 2013). This is a vital competitive challenge for smart cities, which are gaining importance due to increasing urbanization. Young people live with ST, and they are also the bearers of new technological developments that are bringing innovative solutions. The goal of these new hardware and software solutions is making progress for online social relations. Their behaviour in the complex environment is designed in the model of the smart model-based governance by social systems thinking (Figure 1). The development and implementation of the ST is and will be influenced by social and economic changes and opening new social and ethical problems in the near future because ST are now:

- invading sensitive human areas and allowing others to access sensitive, private information in real time; and
- robots will replace humans in more demanding work processes (Mesko et al., 2017).
The model aims to present strategies and key factors that are important for the main conditions for human governance of the ST implementation and their influence on the co-creation of value for the quality of human life.


Generation Y was characterized as a Google web-literate generation (Williams and Rowlands, 2007) by which the presence of information and communication technology did not result in improved skills for accessing information, searching for information, or evaluation (Rowlands et al., 2008). They did not recognize all the software capabilities, and they did not have enough knowledge about how to use applications for problem-solving (Bullen et al., 2008). Students who belong to Generation Z use different technologies for communication, learning and being constantly connected on social applications. They are using technology for personal empowerment and entertainment, but not all of them have satisfactory digital literacy, which would enable them to create new knowledge and not only to consume it (Kennedy and Fox, 2013). From this perspective, it is essential for all providers of services and products to be aware that a generation of digital native’s/network youth has entered academia and the labour market. Technology allows them to be members of different networks simultaneously, and this makes them distinct from the previous generation. They prefer using the internet, and smartphones have become an essential part of their lives. However, smartphones as devices alone do not suffice. Members of Generation Z are finding their place in society by using social media applications with which they can express themselves (e.g. Instagram, Facebook, Snapchat, YouTube, WhatsApp, ooVoo and Jott; Ozkan and Solmaz, 2015).

This generation is private, education-oriented (especially for lifelong learning), professionally fully integrated into the internet environment, and has a great deal of knowledge about new technologies (Pérez-Escoda, 2016). Internet technology also has...
negative impacts on Generations Z and Y, such as the prevention of physical contact and physical activities; reductions of certain cognitive skills; and increased levels of depression, isolation and laziness (Issa and Isaias, 2016).

2.3 Emerging “smart” technologies and the complexity of systems
This paper focuses on the complexity of the emerging “smart” technology paradigm, which has become common in recent years. The authors wish to develop theoretical foundations about the phenomena of studying the behaviour of the representatives of Generation Z and their view of the future significance of ST, primarily on the basis of social systems thinking, which is useful in understanding the social process of governance (Jackson, 2003).

The growth of ST in the time of Industry 4.0 (from 2011 onward) has caused communication activity to move from the natural environment to cyberspace; communication between machines themselves has increased greatly (Cooper and James, 2009; Ning and Liu, 2015).

In this context, both owners of the cyber space infrastructures and users of these systems must be aware of the potential for misuse of information; consequently, it will be necessary not only to provide strict ethical rules for people who access this data (e.g. sensitive personal information) but also to provide high levels of physical and electronic protection.

In recent years, ST have been taking an essential role in interactions between social structures and their digitalization processes (Roblek et al., 2013). Content follows multi-perspective research, where it has been taking five different viewpoints related with information processing capabilities: analysing, consuming, creating, sharing and storing content in private and professional lives. Accordingly, the goal of the present research paper is to present the nature of the problem stemming from the rise of service systems thinking (Maglio and Spohrer, 2013) with an emphasis on the meaning of ST and their influence on the co-creation of value for the quality of human life that is influenced by the three systems that are presented in Table I (Ing, 2013; Spohrer and Maglio, 2010).

Technology has become an indispensable factor in all three systems. Knowledge of its impact, meaning and problems are intertwined through all systems, and certain specific knowledge from each system can aid in understanding the complex problem of the other system, thus enabling a complex course of organizational and social changes that occur in all systems due to the increasing implementation of ST.

If the third industrial revolution was based on the building of social relations through networking (e.g. platforms like Facebook), in the fourth industrial revolution social relations

<table>
<thead>
<tr>
<th>Type of the cyber system</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systems that move, store, harvest and process</td>
<td>Transport, water and waste management; food and global supply chains; energy and energy grids and Information and communication technology infrastructure</td>
</tr>
<tr>
<td>Systems for enabling emergency response, infrastructure, people health, defence, wealth and smart</td>
<td>It is going for a soldier equipment system, detection and surveillance systems. Weapons systems, intelligent vehicles and traffic control, intelligent structures and pavements, financial system including banks, retail, tourism and hospitality, medical care, educational system (from primary to the universities)</td>
</tr>
<tr>
<td>Governing systems</td>
<td>Include on micro-level cities and regions and on a macro-level states and nations</td>
</tr>
</tbody>
</table>

Source: Authors adaptation according to Ing (2013); Maglio and Spohrer (2013)
will be formed through the building of collective intelligence, which will be discussed in the next subchapter.

2.4 Collective intelligence
Knowledge and information have become key factors for success in the twenty-first century (Dominici et al., 2016; Peppard and Ward, 2016). Network economics considers integration as a strategic instrument that affects the production of knowledge and the increasingly important role of information with the implementation of the collective knowledge that is created, accumulated and refined in collective learning (Maier, 2007; Kaschig et al., 2016; Héraud, 2016). As such, collective knowledge is essential to the modern knowledge society and is constituted from the culture (Mantzavinos, 2001), institutions (Biddle, 1990) and technology (Boisot, 1998). A learning network provides students and white-collar people with physical or cyber platforms. Learning networks have (with the accessibility of the high-speed internet, the development of information technology and the implementation of artificial intelligence) moved to the virtual/cyber world; and users now use mobile or social learning platforms, learning management systems and training/education apps that enable them to gain, enhance and share their knowledge and skills on the go (Huang et al., 2013; Ning et al., 2016). This is about the processes of enhancing collective intelligence (Brown and Duguid, 2017; Ning et al., 2016).

Collective intelligence can be defined as a systematically prepared multi-level relation and collaboration strategy, which, among other things, determines the potential of individuals (e.g. their families, friends and business connections), companies and organizations in an individual network or outside it (Joore and Brezet, 2015; Van Der Vegt et al., 2015).

Collective intelligence is based on a process cycle in which procedures and rules for establishing, sharing, processing, analysing and saving intellectual capital emerge (Lee, 2016). The main goal is to generate knowledge and enable the intelligent, analytical tools that will provide exactly that kind of knowledge that will be needed according to the analysed situation at a given moment (Gentry, 2016). The collective intelligence building requires multidisciplinary and interdisciplinary knowledge, collaborative business models and approaches, digitization of business operations and other conditions that allow the growth of collective intelligence (Newman et al., 2016).

3. Methodology
Qualitative research does not aim to find conclusions that can be generalized based on a representative sample. The aim is to gain an insight about a studied phenomenon and grasp the variety within the studied structure. Researchers do not study the frequency of occurrence or the relationship between variables (Vogrinc, 2008). The representative sample of students was chosen to gain in-depth understanding of future management professionals entering the workforce, called “Generation Z” as the first generation that has never experienced life without the internet. Tight (2012) stated that when researching students’ experience within contemporary higher education research, the “attention turns towards the students’ perception. This should be an area of great interest to those working in or concerned with higher education.”

3.1 Purposeful selection
The sample needed to be relevant for our research questions (Engel and Schutte, 2005). Non-numerical review and interpretation is suitable for processing large amounts of unstructured primary data to research underlying meaning and patterns of relationships
(Babbie, 2007). The authors developed the research design together and triangulated the questionnaire design and analysis.

3.2 Data collection
Data were collected at the Faculty of Economics, University of Ljubljana at the Foundations of Management and Organization course, where around 200 students considered ST as one of their homework reflections. A total of 144 students handed in their reflections on ST. The assignment instructions were as follows: Vision of the world: What do you imagine under the term ST (ST)? What would you select under the framework of ST? Which ST tools do you use? Which ST tools do you think you will use in the future? How will ST influence our communication with the environment in the future (your private communication and your connection with the environment in terms of gaining information, control of children, communication with doctors, life-long learning, your business communication with partners and colleagues)? Business students answered the questions in 1-2 pages.

3.3 Data analysis
Narrative analysis (Keats, 2009; Sfard and Prusak, 2005) is a vital part of understanding the construction of the narrative. The authors derived thematic analysis (Roblek, 2009) using thematic networks that facilitate the disclosure of the individual steps in the analytical process, while also aiding in the organization of analysis and the presentation of the results. The most important feature of the analysis was to create a category, on the basis of which the acquired data were structured. It is essential that individual category allows classification of the gained data, given the importance of the meaning of the codes. The definition of this was done on the basis of the units of analysis that were obtained from primary data (Easterby-Smith et al., 2005). The thematic network helped us as an analytical tool in the study and interpretation of the theme and content of our research. Coding was a key process in the analysis of the thematic network, which was used for the generalization of the qualitative data (Creswell, 2003). We have used the technique of a thematic network in three phases (Roblek, 2009): narrowing down the narrative; exploitation of the narrative; and interpretation of the themes. The data analysis process was divided into three sections: data reduction or breakdown of the narratives, discovering meaning, and integration of research findings. The characteristic that appears in all three categories is the interpretation. It was difficult to distinguish between different levels of abstraction in the thematic network (Stirling, 2001). To make the analysis clearer, we also incorporated proof citations (Langley, 2012). We provide the results of our study in a graphical model (Figures 2 and 3).

![Thematic network](image-url)

**Figure 2.** Thematic network – ST usage perception (1)
3.3.1 Evaluation of the smart technologies concept in the present knowledge management processes. Based on the research of Henderson et al. (2016), the authors have identified practice themes in the sample of students and provided proof citations for how students use or intend to use ST in their studies and knowledge management. The students focused on the functionality of the ST, as all the applications enable the more efficient usage of their resources (Table II).

3.3.2 Evaluation of the influence of the smart technologies in the private and professional lives of the business students in the future. In terms of the benefits of ST usage, ST warns us and is our reminder and helper in performing our work and personal activities:

ST evolves through time, and every day something new arrives on the market, more innovative and enables people an easier life, even though we become lazier, some addicted, asocial; however, we must admit to ourselves that ST makes work easier for us, businessmen, teenagers, and the elderly (MT).

ST has influenced a:

Great deal the way we communicate […] it influences the way we express our emotions, our relationships with our family members, friends, teachers, […] the way we talk and write has changed (SL).

Based on the work of Johannessen et al. (2017), we have researched the narratives for ethical issues that students perceive in the future ST usage for our society as a system. Students perceive “life in front of the screen” (SV) as one of the disadvantages of ST usage, as it takes time away from physical presence with their family and friends. Students distinguish the usage of ST in business and personal life and perceive more advantages in terms of business usage (KN): “I think that growing up with ST is not suitable for children as they are addicted to games early on”.

In the business world, ST is especially useful. Employees can exchange information very fast and easily.” Students are also critical regarding authentic communication in the business setting (KZ):

Communication the business world is easier, however virtual communication has bad consequences on the relationships among business partners and co-workers, as they cannot establish authentic relationships that would give a person a sense of loyalty.

In the future, the students state that (KU): “I expect to use computer systems more. I see great advancement in appliances for virtual realities where a human being can “do magic” in the privacy of his/her home.”
Another ethical dilemma relates to efficiency and was termed the “stupidification” effect of ST on humans (SE):

One other bad thing about ST is that it makes people stupid. Instead of writing down words, we write them into our smartphone and it warns us about an upcoming event that we have. Also, for counting, we use a computer and not our own brains. Also, house cleaning we do with the help of ST, such as robots, with just one click we can clean the whole apartment while we rest on the sofa.

The benefits of collective intelligence as a systematically prepared multi-level collaboration strategy that determines the potential of individuals (e.g. their families, friends and business connections) in an individual network or outside it (Joore and Brezet, 2015; Van Der Vegt et al., 2015) have been identified as the following:

- According to Generation Z, ST enables quick feedback that improves their collaboration with others “ST enables you to quickly see the person and you receive quickly feedback”.
- It offers independence: “electronic appliances enable users to independently access, work on and give information from the outside world”.
- Enables consecutiveness: “With the mobile phone, we are connected with all the people we know”.

<table>
<thead>
<tr>
<th>Practice</th>
<th>Digital devices</th>
<th>Description (proof citations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizing and managing the logistics of studying</td>
<td>computer, mobile</td>
<td>Users benefit from ST in autonomous reception, adaptation and forwarding of gained information from the outside world and internet (SB)</td>
</tr>
<tr>
<td>Flexibility of place and location</td>
<td>computer, mobile</td>
<td>Usage of ST in the lecture rooms enables better participation of students and enables online lectures (MJ)</td>
</tr>
<tr>
<td>Researching information</td>
<td>computer, mobile</td>
<td>Students will no longer need to gain their education in institutions but will gain their knowledge through apps (ON)</td>
</tr>
<tr>
<td>Time saving</td>
<td>mobile</td>
<td>ST enables us fast communication with the people through social networks and we always carry in our hands mobile phone (LS)</td>
</tr>
<tr>
<td>Supporting basic tasks</td>
<td>mobile</td>
<td>Phone serves me as a communication appliance, for surfing the net, I use it as a waking device. I also use applications for arranging photos, digital cards for different stores, Gmail and applications for arranging documents (ZN)</td>
</tr>
<tr>
<td>Reviewing and revising</td>
<td>mobile</td>
<td>Internet offers us vast pool of information to which we can access through many devices that make solving our problems easier. In every moment, we can expand our horizons through solving tests, exercises and online courses (SS)</td>
</tr>
<tr>
<td>Communicating and collaborating</td>
<td>mobile</td>
<td>People communicate more openly when they are hidden behind a virtual identity (MS)</td>
</tr>
<tr>
<td>Seeing information in different ways</td>
<td>computer, mobile</td>
<td>Internet is an excellent source of acquiring and exchanging information in online learning (SV)</td>
</tr>
<tr>
<td>Cost saving</td>
<td>computer, mobile</td>
<td>Important result of ST is also saving, not only resources (water, clean air and soil) but also time, that we can better use (CL)</td>
</tr>
</tbody>
</table>

Table II. Usage of ST in knowledge management process
3.3.3 Students and their application of the knowledge management processes through different smart technologies. Students identified many different ST appliances that they know or use, such as, smartphones, smart tablets, smart watches, smart houses, smart sensors, smart robots, smart cars, smart home appliances, smart toothbrush, smart cameras, smart sensors and smart glasses. Even though sharing knowledge will be easier, this presents the ethical dilemma of how knowledge and what kind of knowledge is shared (KK): “I think in a couple of years we will not have such private lives as we do today”.

Among the personal and contextual factors, opinions of emerging ST, and self-regulation behaviours, contextual, educational factors most influence students’ use of emerging ST to consume, create and share contents in their private and professional lives as their homework assignments require them to search information on the internet, online scientific databases, communicate with professors, submit assignments and track their studies through online study systems.

Do people nowadays know how to exist without ST? According to the sample of students, the answer is “no”. Personal factors affect the usage of ST, such as preferences about tracking technological advances (DE), and desires for multi-functionality (DN). Contextual factors are mostly connected with the internet being accessible practically everywhere in the developed world (HK): “Technical appliances will replace human labour and reduce workforce and workplaces”. Students’ opinions of emerging ST are various, and they are aware of the advantages as well as disadvantages of using ST (PN):

It is not a problem that ST exists, but a problem lies in the way people become when they use it. In the past we socialized with our friends; wherever you went you saw children in the parks and this is no longer so.

In terms of self-regulation, students mention the influence of age, generational aspect (BT):

I think that in the future ST will not so much influence the communication with the doctor or business partners. In companies and hospitals, people who have not grown up with ST work. They know ST, but not the way the majority of youth do.

4. Discussion
The analysis of the potential impacts and complex issues is based on the theoretical concept of the soft systems methodology. The research is focused on the activity (specifically that of Generation Z) in cyber smart systems and offers a view into the social system that includes behaviour and complex social issues. The evaluation shows the potentials of ST and their impact on the social environment in the present and future. It is about a never-ending process in which human attitudes and perceptions must be continually explored, tested and changed, according to Checkland (1999).

Students mostly use ST to save time while studying and in their free time. ST is part of their lives, and there is evidence that it is so intertwined with their studies, work and spare time that students can no longer conceive of their lives without it. This carries important implications for the ethical considerations of ST usage.

Students are surprised by how ST developed and are cautious about imagining how the technology will change and affect their lives. They are concerned about several ethical
dilemmas of using it, such as privacy and spending time with their loved ones and friends. In the future, the students imagine an even larger impact of ST on their lives. As they perceive that ST has “no end” in its development, they envision that regulation will need to be put in place to monitor it.

In line with previous research (Sommer, 2015), business students mainly perceive ST-connected technologies to be those that include sensors and cameras and are already a part of new vehicles, homes and kitchen appliances. Our research, similarly to that of Rauschnabel et al. (2015), has shown that young people are key ST adopters. Findings show that business students have difficulty in evaluating the acquired information on the internet, which is in line with Jones and Shao (2011). Students used ST for keeping contact with friends and family, entertainment and knowledge acquisition and would need more support for creating new knowledge and not merely consuming it, which is in line with the research of Kennedy and Fox (2013). Business students also use social media applications for maintaining contacts, building networks and expressing themselves, which is in line with the research of Ozkan and Solmaz (2015). Our findings state and confirm previous research that business students' communication is moving from the natural environment to cyberspace and communication between machines themselves (Cooper and James, 2009; Ning and Liu, 2015). Business students perceive the functionality and usefulness of ST; therefore, ST develops society in technical, organizational and socio-political forms, as McLeod and Doolin (2012) stated.

The proposed factors include personal and contextual factors, opinions regarding emerging (smart) technologies and self-regulation behaviours. Future decision-making of the students will be guided by convenience principles and saving resources and time. Students perceive their self-organization in the future as very dependent on the availability of ST in institutional settings, such as educational and business processes, as well as their personal lives. Students perceive the future social system dynamics in terms of socialization and losing personal contact with their friends and family as the main threat. They perceive it to be difficult to predict new developments in ST, as they think progress will continue. They perceive future violations of privacy and health issues to be the main ethical issues connected with the usage of ST.

Our research study poses a new conceptualization of ST as social innovation, which provides a new research path. We developed theoretical foundations of the behaviour of the representatives of Generation Z and their view of the future significance of ST, primarily based on social systems thinking and identifying ST as a social innovation. We have demonstrated that ST enables collective intelligence building and gaining multidisciplinary/interdisciplinary knowledge, digitization of study and future business operations. We highlight the ethical dilemmas connected with ST; as sharing knowledge will be easier with time, it is also important to research how knowledge is being shared and what kind of knowledge is being acquired. We state in our findings that the quality of knowledge gained with the help of ST is not necessarily better and needs the facilitator to organize, lead and evaluate the benefits of such knowledge.

ST is a social innovation if the new idea has the potential to improve the quality or quantity of life (Pol and Ville, 2009). On 25 September 2015, 193 members of the United Nations General Assembly formally adopted the 2030 Agenda for Sustainable Development, along with a set of 17 Global Goals, underscoring the fact that businesses are agents of change. However, businesses are led by people; therefore, our research helps managers to recognize what (dis)advantages business students perceive in ST so that managers can improve the current ST environment. ST enables achieving the Global Goals of quality education, gender equality, decent work and economic growth, the development of industry,
innovation and infrastructure; and reduces inequalities. Global Goal Number 9 emphasizes building resilient infrastructure, promoting inclusive and sustainable industrialization and fostering innovation by clearly stating the aim of significantly increasing access to information and communications technology and striving to provide universal and affordable access to the internet in the least developed countries by 2020 (United Nations, 2015).

Our research provides the answers to our research questions regarding how fast development in the past few years has impacted our human lives, specifically the lives of business students who are future workers. We provide suggestions for finding solutions for consequences, such as ethical dilemmas in using ST. Higher institution educators need to raise awareness regarding responsible usage of ST in the classrooms. By following the Principles of Responsible Management Education (PRME), we offer knowledge about the impact of ST on individuals and society as a whole. Since its early initiatives in 2007, PRME, which is supported by the United Nations, has discussed and sought ways to educate the new generation of business leaders who will be equipped and capable of handling the complex demands of organizations and societies in the twenty-first century. We focus particular attention on the systemic complexity of the possible problems to which business students are exposed.

5. Conclusions
In this paper, a road map of a few possible ways of using ST among students is offered. The findings can be useful for professors, specifically because it is necessary, from a didactic perspective, to identify different learning methods useful for their students. Some studies have been conducted on the perception of ST, but none on business students’ perceptions about using ST. For this reason, in our study, we have focused on the business students’ use of contemporary ST and their opinion about the impact of emerging (smart) technologies to new forms of communication, acquisition and dissemination of information now and in the next 20 years. The contribution of our study is the widened understanding of the usage of ST among business students. They are cautious when imagining how the technology will change and affect their lives. They fear several ethical dilemmas about using it, such as privacy and the effects on spending time with their loved ones and friends. Students perceive their self-organization in the future as very dependent on the availability of ST in institutional settings.

In comparison with the previous research, we provide in-depth research of ST in the framework of social innovation that refers to new ideas that resolve existing social, cultural, economic and environmental challenges for the benefit of people and the planet. A true social innovation is systems-changing: it permanently alters the perceptions, behaviours and structures that previously gave rise to these challenges (Centre for social innovation, 2017).

Practical implications of the research are in understanding the perception and usage of ST of Generation Z, with which contemporary managers are unfamiliar. Managers face unpredictable challenges in their day-to-day activities that are even deepened by ST. Usage of ST offers an impact on managers as well, helping them to develop effective management practices in their professional teams. This can contribute to innovative problem-solving. Moreover, managers must make an effort to create an efficient learning environment in which their employees will feel socially supported and, therefore, also satisfied.

Despite its contributions, this study is not without limitations. They are mainly related to the self-reported nature of the data gathering. The study variables were all self-reported within a single course at one faculty. The findings of our research are based on the students’
qualitative answers to the questionnaire. For the purpose of our study, we focused on only the previously mentioned sample. Further research should be focused on deeper and wider investigation of this topic and could include case studies of students’ perception about using ST across the globe and their views on the development and usability of them with both qualitative and quantitative data. Our study could also be extended to researching lecturers’ perception of ST and their usage, as they also are exposed to constant technological changes.

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Towards a systems thinking based view for the governance of a smart city’s ecosystem

A bridge to link Smart Technologies and Big Data

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Abstract

Purpose – This paper aims to investigate the role of Smart Technologies and Big Data as relevant dimensions in affecting the emerging social and economic dynamics of society with the aim to trace possible guidelines and pathways for decision makers and researchers interested in the governance of the Smart City’s ecosystem. The increasing attention to the domain of technologies and the amazing scenario that is emerging as a consequence of the influence of Smart Technology and Big Data in everyday life require reflection upon the ways in which the world is changing.

Design/methodology/approach – The paper adopts the interpretative lens provided by the systems thinking to investigate the challenging domain of the Smart City. A qualitative and interpretative approach is adopted to reflect upon the role of technologies in everyday life.

Findings – The Smart City ecosystem is defined as a multilevel construct useful for understanding how technical and technological dimensions of the Smart City can be managed not only as supportive instruments but also as key pillars to support, facilitate and ensure an effective cognitive alignment among all the involved actors.

Originality/value – This paper provides a tangible evidence of the systems thinking contribution in analysing, understanding and managing dimensions and paths of social dynamics. A contribution to previous studies is provided with reference to systems thinking, Big Data and Smart City.

Keywords Smart city, Big data, Systems thinking, Smart governance, Smart technologies

Paper type Conceptual paper

1. Introduction

According to several managerial contributions, the twenty-first century is the era of technology innovation, information sharing and hyper-connected societies (Castells, 1999; 2010; Shaw, 2002; Karakas, 2009; Webster, 2014; Barile et al., 2015a, 2015b). All the traditional social and economic rules are progressively changing as a consequence of the fast evolutions in the challenging scenario in everyday life (Van Dijk, 2012; Del Giudice et al., 2016). The emerging balances are showing an increasing relevance of technology and information as relevant drivers on which companies, organisations and institutions should “act” to improve their performances and opportunities for survival (Davenport, 2013; Evangelista et al., 2016).
The information is the new “key resource” for social and economic actors, and the information and communication technologies (ICTs) offer the instrument to better acquire, analyse and use it (Lopez-Nicolas and Meroño-Cerdán, 2009).

Building upon these reflections, several managerial contributions have analysed the domain of information with the aim to better explain its dimensions (Miller, 1996; Garson, 2000; Siponen, 2001) and processes (Alavi and Leidner, 2001; Applegate et al., 2007; Davenport, 2013) and several researchers have highlighted the role of ICTs in supporting the information acquisition (Mansell, 1999; Roberts, 2000) and sharing (Hendriks, 1999; Steinmueller, 2000; Caputo et al., 2016b). By following this approach, an increasing attention is emerging with reference to the topics of Smart Technology in terms of a “self-operative and corrective system that requires little or no human intervention” (Haque et al., 2013, p. 22); and of Big Data as “high-volume, high-velocity, and/or high-variety information assets that require new forms of processing to enable enhanced decision making, insight discovery and process optimization” (Chen and Zhang, 2014, pp. 314-315).

Despite the relevance of these topics, they define a perspective strictly focused on the technological and instrumental dimensions of society and really little attention is paid in reference to the role of the actors involved in the information building and sharing process (Cook and Das, 2004; Caputo et al., 2016a, 2016c; Perko and Ototsky, 2016). According to several contributions offered with reference to the domains of Smart Technologies and Big Data, society should be analysed and managed by building efficient digital platforms able to ensure better links among the many dimensions involved in social and economic processes (Uotila and Melkas, 2007). Unfortunately, the reality is more complicated than this (O’Connor, 1994; Espejo, 2015).

As underlined by Bijker and others (2012), technologies can explain only a small part of the “social complexity”. In the same direction, Steinmueller (2000) underlines that information can only by partially decoded by using the technology because a large part of their meaning is embedded in human resources and they cannot be shared by simply using a technological platform. Johannessen and others (2001) outline that technologies are useful to improve the quality in management of more “tangible” dimensions of human life, but (for now) they are useless in understanding and managing cognitive and psychological variables.

In accordance with all these contributions and embracing the interpretative perspective of social sciences, a relevant research question is required to be investigated: How do Smart Technologies and Big Data affect everyday life?

With the aim to propose a possible answer to this question, the paper adopts the interpretative lens offered by the systems thinking and service logic to clarify the role of smart and digital environment in society life. An inductive approach is adopted to catch the relevant contributions that systems thinking can provided in understanding and managing some key concepts related to the domain of Smart Technologies, Big Data and Smart Cities. Accordingly, the research path has been structured by adopting a sequential approach in which the conceptual umbrella provided by systems thinking has been used to define a possible new interpretative path with reference to the role of Smart Technologies and Big Data and then, afterwards, discover ways to support the application of this new path with reference to the Smart Cities’ logics and dynamics. Reflections herein are contextualised with reference to the domain of the Smart City as relevant examples of contribution among social and technological dimensions. Finally, implications, conclusions and future directions for research are presented.
2. Theoretical and conceptual background

2.1 The contributions of systems thinking in investigating Smart Technologies and Big Data

The society could be defined as a complex set of relationships based on the continuous sharing of resources and on the combination of several expectations culminating in the building of new value. All these elements make the society a domain that cannot be analysed by simply investigating its dimensions; they require an adoption of an interpretative lens that is able to outline how different elements interact by building conditions of “reciprocal influence” over time (Bandura, 1978; Di Nauta et al., 2015; Turoff et al., 2016). According to this view, society cannot be analysed in the light of a mechanistic approach; it requires the adoption of a holistic perspective able to link all the involved elements and pathways in a common “interpretative picture” (Odum and Barrett, 1971; Jackson, 2006; Hammond, 2010).

Building upon this assumption, systems thinking represents the better approach to understanding how all the elements and relationships in society are linked and evolve over the time (Cutcliffe, 2000; Caputo, 2016). The systems thinking approach supports the shift from a reductionist and mechanistic approach direct to explain how elements are composed and related to a holistic and dynamic view in which the attention is also on the elements that affect the emergence and the evolution of the whole phenomenon (Barile et al., 2016; Perko and Mlinarić, 2016).

The systems thinking approach offers several relevant contributions to better understand how an entity is able to organise itself (Maturana, 1975; Varela, 1984) by sharing resources with the “external” environment (Espejo, 1990) to achieve conditions of survival (Beer, 1979; Barile, 2009). Among the contributions offered by the systems thinking approach, two research domains appear to propose relevant advancements in knowledge in understanding social dynamics: the viable system model (VSM) and the viable systems approach (VSA). While the first one clarifies how the elements involved in an organised entity are able to define conditions of reciprocal influence by building a shared balance (Beer, 1979, 1984, 1985; Espejo and Harnden, 1989; Espejo et al., 1996, Espejo and Reyes, 2011), the latter proposes a general representation of systems based on its information variety useful to investigate any kind of organised entity designed to survive in a specific environment (Barile et al., 2014, 2016; Saviano et al., 2014).

Specifically, the systems thinking – thanks to the contributions offered by the VSM and the VSA – enriches previous knowledge in managerial domains by underlining the relevance of cognitive dimensions in affecting a system’s decision and behaviours (Espejo, 1992; Barile et al., 2013). At the same time, it highlights that it is not possible to define an objective view of reality because it is subjectively affected by the observers’ perspectives and need (Saviano and Caputo, 2013), and it defines useful guidelines to better represent the link among the elements that formed the system (Barile, 2013).

As shown in Figure 1, adopting the interpretative lens offered by systems thinking emerges the relevant role of Smart Technologies in supporting the alignment among the different elements involved in a system by ensuring a fast reciprocal adaptation over the time (Streitz et al., 2005; Di Fatta et al., 2016), and also seen is the key role of Big Data as pathways to ensure the building of a strong feedback process able to increase the alignment between the linked systems (Wu et al., 2014).

In such a perspective, the systems thinking offers the opportunities for defining a shared conceptual framework in which technological and social dimensions are effectively linked (Polese et al., 2016; Saviano et al., 2016a). It underlines the need for enlarging the perspective both in technological and social studies to build better bridges among human resources and technical instruments (Barile et al., 2015a, 2015b; Saviano et al., 2016b). By adopting the systems perspective, it is possible to state that the advanced technologies are not smart
themselves, but they become smart only if they are aligned with users’ ability when using them to solve their needs (Caputo, 2018). Moreover, the automatised processes are suitable only in the case in which there is a shared expectation, but they are useless in every case in which involved actors have different needs and/or perspectives. Finally, when the environment is subjectively built by the system then technologies can produce effective, efficient and suitable solutions – but only in the case in which they are based on an in-depth study of variables and elements that address the systems’ perceptions.

According to the contribution of systems thinking, it emerges the “relational nature” of Big Data and Smart Technologies as key levers able to produce effects only as a consequence of actors’ participation and collaboration. In such a vein, the way in which actors involved in the same system interact using Big Data and Smart Technologies requires investigation. A possible interpretative contribution, in this way, is provided by the service logic as detailed in the next section.

2.2 The service perspective for Big Data and Smart Technologies
Big Data is being generated by everything around us at all times. Every digital process and social media activity produces it. Systems, sensors and mobile devices transmit it. Big Data are arriving from multiple sources in an alarming velocity, volume and variety. To extract meaningful value from Big Data, you need optimal processing power, analytics capabilities and skills (www.ibm.com/big-data/us/en/).

Over time, several definitions have been provided with reference to the domains of Big Data and Smart Technologies in the light of several interpretative lenses. Some of these definitions are reported in the following Tables I and II with the aim to highlight the multiple perspectives interested to these domains.

Evidently, we can find in every single system a lot of different approaches and processes that produce and analyse data all the time. This is a common feature of all implementation of information technology (Jørgensen et al., 2009). It is necessary to underline that only this fact does not mean anything very significant or remarkable. However, adding this capability to interconnect the devices, we can use, along with following, the analytic processes results in a huge number of combinations which enables the creation of a unique system that proves data and information to run other subsequent systems (Fricker, 1997).

There is no difference in the Smart City environment. Sources of the basic simple data (sensors and basic devices) can also be identified, along with the processes and applications that are analysing them and the companies that are using that data to provide the service for the citizens (Bowerman et al., 2000; Paskaleva, 2009; Cocchia, 2014).

![Figure 1](Image)

**Figure 1.** The role of Smart Technologies and Big Data in systems’ linking

**Source:** Authors’ elaboration
This situation apparently leads to the creation of a new kind of environment for following stakeholders:

- Customers – city citizens, who are the final receivers of the service;
- Industry – that can be also represented by the municipality services, who are trying to improve their service level using the application of Big Data; and
- Developers – companies or/and individuals who are developing applications (mobile or web) according the order of the industry for the sake of the customers.

There are two main questions to answered:

Q1 How the data are used and by whom?

Q2 How the revenue for the data usage is generated and by whom?

The data, provided by the sensors and other devices should be easily accessible by anyone who wants to use them. The city itself should guarantee the free access to data – only via this city’s management ensure political independence, market persistence and standardisation (Vilajosana et al., 2013).

Then, the revenue is not generated by the data themselves but are born by their utilisation. The industry is about to invest in the sensors to get the initial data to be used
and, simultaneously, is pushing the developers to create new and more useful application for their customers. The same principle as on Android or Apple market for revenue generation is used – it is revenue sharing (Vilajosana et al., 2013).

We can easily see that this model of the Smart City is based on the services that are dependent on open data. But the approach, presented above, is focusing just on comparing two variables: data flows and revenues coming from the work with those data flows.

From the service perspective, reflecting the role of ICT, one more important aspect cannot be missed: a value, co-created by the participating parties. The value is not equal to revenue. Revenue is represented by money transfer, but to explain the role of the Big Data in the process of sustainability, there needs to be a focus on the process of the value creation as well.

In the beginning, the basic data are created; data are taken from sensors and similar devices. Those data are collected, processed and offered to customers via several applications, provided by different companies. Customers, or, in general, all users of the application, are also sources of the data (feedbacks, data about their geographical position, searching data, data about their preferences, etc.). Those data are again added to the collection of the Big Data and together with actualised data from sensors are used to provide a new level of the service (Lusch, 2011). As shown in Figure 2, this cycle is potentially never-ending; it ends only in the moment when it would not be able to provide a new value for the customer.

The most important connection is Number 4. It represents the will of customers to participate in service creation. They are not only passive users of the data; they need to provide (and be the source of) new data, actualised and improved by their contribution. This critical factor determines whether or not the service and whole environment will run and be continuously developed.

This also means that the citizens must be motivated not only to use the services but also to participate in their development. They need to understand their position and its importance; and they need to be willing to collaborate. The question is, “How can citizens be motivated to do so?”

With the aim to provide a possible answer to this question, a multi- and trans-disciplinary framework occurs to support a paradigmatic change in the approach to Big Data and Smart Technology. A strong focus on the relational dimension is required, and a better understanding of the role of users in a defined environment should be maintained. In

**Figure 2. The data process**
such a vein, the topics of Big Data and Smart Technology are analysed. Specific reference is made to the Smart City environment to clarify which interrelated elements in a shared structure can generate different systems as a consequence of their ability to build conditions for collaboration and participation.

2.3 The domain of Smart City among users, services and technologies
The Smart City is a term for a city that focuses basically on two main goals. One is a high living standard of its citizens, and the second one is a sustainable development of the city. These main goals can be fulfilled by incorporating and evolving many services that support citizens’ living standards, on the one hand, and help to develop the city and prevent exhausting of sources, on the other. There are many different papers contemplating about Smart City service domains. In addition, there is still no shared agreement on them.

For instance, here follows one of the latest definitions of the Smart City using a distribution of service domains (Mattoni et al., 2015):

- Community - Participation and Communication.
- Environment - Enhancement.
- Energy - Sustainability and Optimisation.
- Mobility - Movement.
- Economy - Dynamism and Innovation.

In other words, a Smart City should support innovations, the use of a new technology, communication (people, services, private and public organisations from different city sectors), citizens’ engagement and knowledge development – all to create a supportive synergistic environment. In such a line, the domain of the Smart City includes a clear representation of several research streams and perspectives interested in investigating multiple aspects of the same concept. These multiple aspects can be represented through three key perspectives related to technology, service and user as summarised in Table III.

Considering the multiple perspectives involved in the domain of the Smart City and the reflections reported in the previous sections, this paper proposes an approach for developing Smart Cities in a complex manner using a framework based on the Management by Competencies (MbC).

MbC is a managerial approach that describes a way of managing a vital company. Vitality in this context means that it is not just successful, but it is constantly successful. Exactly, the definition of the vitality is as follows: *Attaining of current goals does not diminish the chance to achieve goals in the future* (Plamínek and Fiser, 2005). To sum it up, a company following MbC does not drain its possibilities (resources) for a one-time achievement; it is successful in a long-term, and the mean of success is its employees.

Here is an analogy with Smart Cities that aims to achieve sustainable development and focus on lowering energy consumption and renewable sources, on the one hand, and aims to create a city with entertainment and work possibilities for its citizens, on the other.

The main idea, MbC builds on, is an existence of two worlds in companies. There is a world of possibilities and world of requirements. If a link between these two worlds is weak, company balances on the edge of its existence (requirements should reflect possibilities and vice versa).

Using this idea, we developed a Smart City duality model. Each city – regardless of whether it is smart or not – has some requirements (goals) and possibilities (services). What should make Smart Cities different is a way of assessing and reaching goals. Smart Cities’ goals are more oriented to their inhabitants (sustainable city development and high living standard) and can be fulfilled just by the active participation of their communities. Thus,
there are two main units with their possibilities and requirements. The first one is a Smart City itself whose requirements are its goals, and possibilities are city services. The second one is the communities in the city with their requirements (high living standard, and possibilities) human and financial capital.

The whole system works like a cycle. As shown in Figure 2, Smart City goals are fulfilled by communities’ possibilities and their requirements are conversely fulfilled by Smart City services (Figure 3).

<table>
<thead>
<tr>
<th>Perspective</th>
<th>Key concepts</th>
<th>Source</th>
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<tbody>
<tr>
<td>Technology perspective</td>
<td>At the beginning of future cities research, there was the main focus on technology perspective. More specifically, with the development of information technologies and its common use in daily lives, there was an idea to use an advancement of this technology broadly in cities as well. This is how a concept of Digital City was born. Then, this technology attitude was innovated and more oriented on services (e.g. Intelligent city, Ubiquitous city)</td>
<td>Dooley, (1996), Schaffers et al. (2011), Komninos et al. (2013), Perera et al. (2014), Zanella et al. (2014)</td>
</tr>
<tr>
<td>Service perspective</td>
<td>The shift to service orientation means using the technology not just for controlling and sharing information, but to provide better and usually more complicated or complex services. The current services don’t have a broader context in many cases. They are executed separately, which doesn’t utilise a full potential of other services and cities in general. The next step, some pioneering cities are already working on, is to interconnect the services to gain an advantage of more data and an infrastructure</td>
<td>Nam and Pardo (2011), Mulligan and Olsson (2013), Anttiroiko et al. (2014), Piro et al. (2014)</td>
</tr>
<tr>
<td>User perspective</td>
<td>Having a high number of interconnected services can be a good parameter of the city development. Nevertheless, we still miss a proposal of an attitude to create new services, meaning which are of the highest priority and which can be created later. There is no doubt about the services they have to be useful to someone. One of the first questions is, to whom (city government, citizens or even other subjects). We propose to use a framework based on the Management by Competencies® (Plamínek and Fíšer, 2005) to deal with this problem. The framework is not yet completed, but the main idea follows</td>
<td>Cardone et al. (2013), Walravens and Ballon (2013), Carvalho (2014)</td>
</tr>
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</table>
3. Method and research path

The paper builds upon a qualitative approach method to investigate previous managerial and organisational contributions with the aim to provide useful guidelines for better understanding and managing the domain of Big Data. According to Liamputtong (2013), the qualitative and descriptive approaches offer the opportunity for organisation of previous knowledge in new schemes with the aim to understand structure and functions of a new phenomenon.

The choice to adopt a qualitative approach is motivated by the nature of the investigated domain (Denzin and Lincoln, 1994). Smart City is a relatively new topic, and a clear picture about its structure and functioning is still missing (Batty et al., 2012).

With the aim to fill this gap, the paper adopts the interpretative lens provided by systems thinking and service logic to identify a set of key concepts potentially useful for better understanding the domain of the Smart City. After this, the identified concepts are integrated with the aim to build a possible conceptual picture of the Smart City. Finally, this conceptual picture is detailed in the next section, focusing the attention on some dynamics that could represent interesting starting points to investigate the Smart City domain through quantitative approaches as well.

4. Towards an ecosystem view of Smart City as complex adaptive systems

According to Lusch (2011, p. 15), an ecosystem is:

A spontaneously sensing and responding spatial and temporal structure of largely loosely coupled value proposing social and economic actors interacting through institutions and technology, to: coproduce service offerings, exchange service offerings and cocreate value.

As presented, this definition seems to offer a clear representation of the Smart City, as proposed in the previous sections. Specifically, the Smart City can be considered a complex of users, services and technologies linked to ensure a shared satisfaction (Nam and Pardo, 2011).

In such a perspective, a relevant role is played by Smart Technologies and Big Data in ensuring a shared satisfaction of all the involved actors by supporting the fast adaptation of the relationship on which the Smart City is based. Specifically, Smart Technologies represent the instruments to improve the efficiency in the relationships between citizens and city infrastructures and services, while Big Data ensures an effectively adaptation of city services to citizens’ expectations. According to this, Smart Technologies and Big Data can be considered the levers on which to act to build a more efficient approach in the management of the Smart City as a complex adaptive system (CAS).

As underlined by Holland (2006, p. 1), CAS is a system that has “a large numbers of components, often called agents, that interact and adapt or learn”. As shown in Figure 4, by adopting systems thinking, the Smart Technologies and Big Data could support the emergence of Smart Cities aligned with the logic of CAS (Figure 4).

In line with the reflections proposed in the previous sections, Figure 4 shows that by acting on the Smart Technologies and Big Data, it is possible to better understand the relational and transactional network in which the elements involved in Smart City are engaged. Decision-makers can then gain a clear picture about the relationships among the elements involved in Smart Cities. Consequently, decision-makers have the opportunity for understating that individual behaviours and decisions are the result of multiple influences. According to Sterman (2000, p. 8), here emerges the need to:

Improve our understanding of the ways in which an organization’s performance is related to its internal structure and operating policies, including those of customers, competitors, and suppliers and then to use that understanding to design high leverage policies for success.
More specifically, in the light of CAS, the Smart City could shift to be considered an ex-ante planned technological city managed by some kind of “supra entity” to become a multi-dimensional, interconnected domain that can adapt itself through reliance on the support offered by the technologies (Smart Technologies) to respond to citizens’ behaviours and expectations (Big Data). From such a perspective, the elements involved in the Smart City can be considered agent in terms of “semi-autonomous units that seek to maximise their fitness by evolving over time [and able to] scan their environment and develop schema” (Dooley, 1996, p. 3). By adopting this interpretative perspective, it is possible to highlight the high subjectivity that affects the Smart City, and it is also possible to highlight that it is not possible to define an objective representation of the Smart City because for each involved agent, it acquires different meanings.

In the light of the CAS perspective, the Smart City is a relevant example of social phenomenon and its analysis, study and representation requires combining multiple perspectives in a shared interpretative framework to show, by adopting a holistic approach, how agents’ relationships affect its dynamics and evolutions over the time (Bowerman et al., 2000; Paskaleva, 2009; Cocchia, 2014).

5. Conclusions, implications and future directions for research
As it was shown, Smart City development depends on two main factors: continuously updated Big Data and Smart Technologies that are using them as one factor and customer willingness to cooperate on their development.

Data and applications, used to produce more data that are used for the better utilisation of the service and whole service environment. The process seems to be never-ending, depending only on the fact and will of all the stakeholders to cooperate on its sustainable development.

Accordingly, the paper shows that an effective management of the Smart City requires to clarify role and contributions of Smart Technologies and Big Data. In the same direction, the paper underlines the existence of multiple perspectives involved in the management of the Smart City, and it highlights the need for adopting multi- and trans-disciplinary approaches
with the aim to effectively provide a clear picture and framework to the actors involved in the management of Smart City.

Following these reflections, it is possible to state that, from the theoretical point of view, the paper focuses the attention on the opportunities related to the application of systems thinking and service logic as general interpretative frameworks through which several research streams and perspectives can be combined. At the same time, from the managerial point of view, the paper shows the inefficiency of traditional tools and instruments for managing a phenomenon such as the Smart City based on new logic not still fully schematised in the existing “managerial kit”.

Recognising the validity of the proposed concept, some possible future lines of research can be tracked with the aim to clarify the reasons that motivate users in sharing personal data through the use of Big Data and Smart Technologies that are also in the domain of the Smart City.

Reflecting upon these research streams, some implications can be derived both from theoretical and practical points of view. Specifically, from the theoretical point of view, it emerges the need for defining innovative approaches and instruments to better investigate the role and dimensions of Big Data and Smart Technologies that rely upon the users’ perspective with the aim to explain social and economic changes produced by their use. From a practical point of view, managerial and organisational knowledge is enriched with new instruments able to face the emerging challenges imposed by the complex domains of Big Data and Smart Technologies in the light of their cognitive influence on users’ decisions and behaviours.

Accordingly, the reflections herein are only directed towards outlining a possible conceptual path in which borders and boundaries require to better definition because of the multiple connections and influences that can be traced among the identified concepts. Specifically, more studies should be developed to effectively understand how Big Data and Smart Technologies can affect the sustainability of business and social processes with the aim:

To move from generalizations about accelerating learning and systems thinking to tools and processes that help us understand complexity, design better operating policies, and guide change in systems from the smallest business to the planet as a whole (Sterman, 2000, p. 4).

References


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Analysis of crowd stampede risk mechanism
A systems thinking perspective
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Abstract
Purpose – The purpose of this paper is to analyze the crowd stampede risk mechanism from the perspective of systems thinking.
Design/methodology/approach – Causal loop diagram is drawn to outline the non-linear interactions among complex factors across the whole system and dissect the contributory factors of crowd stampede accident. To systematically construct the theoretical framework and find fundamental solutions, co-word analysis with Citespace is used to get the critical data. An agent-based simulation using Pathfinder is conducted to develop a spatial model for the Shanghai Stampede Accident that happened in 2014.
Findings – The causal loop diagram is formed to not only illustrate the symptomatic solutions with a quick fix but also dissect the fundamental solutions through an underlying systemic analysis. The simulation shows that crowd stampede experiences an interactive process of accumulation, trigger, delay, break and diffusion of risk factors within the crowd system. A linkage effect among the multidimensional characters of individuals and the system accelerates the stampede risk deterioration. There exists delay of the result of effect from the deep-level measure.
Practical implications – A top-down approach is offered to policymakers for crowd stampede risk protocol design and synergic emergency control that may reduce the risk of the stampede.
Originality/value – In this study, SDFT paradigm is proposed as the critical solution for the crowd stampede accident. In addition, a chain effect of energy and a linkage effect within the crowd system is illustrated for in-depth understanding of crowd stampede risk.
Keywords Simulation, Systems thinking, Accident analysis, Causal loop diagram, Crowd stampede risk

1. Introduction
The crowd stampede accident (CSA), a mass gathering hazard, frequently occurs during public events in recent years around the world (e.g. 1,426 people died in the CSA when passing through the pilgrimage tunnel in Mecca in 1990; 375 people were killed in the CSA during celebrations due to the rumor and panic in Cambodia in 2010) (Dupuy, 2005; Helbing et al., 2000; Shen et al., 2012). Sometimes, the CSA is triggered in life-threatening situations, mass gathering, the rush for aid or seemingly without causes (Lai, 2017). As pedestrians are involved in a complex interaction system including individual behaviors, crowd movements, surroundings, etc., unpredictable chain consequences usually accompany the crowd
disasters. Thus, how to recognize the risk indicators of crowd members in advance and design the risk protocol of activities has become an important issue.

Crowd modeling and simulation have been proved to be an effective method to program pedestrian behavior and access crowd risk. Plenty of models are proposed to describe the nonlinear dynamics relationship where the pedestrians interacting with each other. Sociopsychological and physical forces are utilized to explain the interaction within the panic crowd in the social force model (Helbing et al., 2000) which has been modified by many researchers to analyze pedestrian behaviors or crowd flow (Guo, 2014; Hou et al., 2014). Cellular automaton models reflect simpler rules and calculation efficiency (Burstedde et al., 2001). Both time and space are considered during modeling. In complex network models, space is divided into separate areas. Occupants are treated as moving from room to room, but the method is difficult to program the pedestrian movement, e.g. overtaking and evading, mostly used in crowd counting and evacuation routing (Cova and Johnson, 2003; Jiang et al., 2016). Fuzzy theory-based models are well-developed complex algorithms to handle uncertainties by linguistic rules under the condition of pedestrian traffic (Fu et al., 2017; Zhou et al., 2016b). Agent-based models treat pedestrians as virtual agents which are designed to obtain some basic forms of intelligence and emergent capacities. The actions of agents are affected by the surroundings based on multi-loop feedback systems (Jia and Yun, 2014). Some other models, such as magnetic force models and fluid models, are also adopted to depict crowd dynamics. These original models just focus on certain parts of crowd dynamics. However, ST perspectives and paradigmatic analysis of the CSA are rarely mentioned.

It is generally acknowledged that our cognition of accidents is defective, and they randomly occur within the constantly changing environment. This arises not as a criticism of our limitation; rather, it unfolds the randomness, variability and evolution of the accidents (Allison et al., 2017). Thus, to some extent, the implementation of effective analysis approach is critical to enriching the cognition of the underlying causes and solutions of CSAs.

ST is defined as a compound theory that can integrate diversified approaches and various components to analyze complex situations (Argyris and Senge, 1990; Mella, 2012). It is widely used as the critical approach in management research, including engineering programs, quality management and risk management, to dig the complexity of the problems (Batat and Prentovic, 2014; Vidal and Marle, 2012). Particularly, in dynamic domains such as accident analysis, an ST perspective is irrefutable and dominant, which is recognized as generic archetypes that introduce the systemic structure of diversified states. It focuses on the notion that an accident is not an occasional or linear attribute arising from burst probability, but non-linear interactions among complex factors across the whole system (Adamatzky, 2005). The foothold of thinking as the result of unexpected, complex relationships among system components is required, rather than isolated constituent parts. The perspective of systematic models is widely exemplified to provide the development of risk management, such as Accimap framework (Salmon et al., 2012), Swiss Cheese Model (Underwood and Waterson, 2014) and STAMP (Allison et al., 2017).

The novelty of this research is the establishment of a comprehensive and non-linear approach based on causal loop diagram (CLD) which forms the main framework integrating co-word analysis and agent-based simulation. The potential risk factors of the CSA are proposed with SDFT paradigm through a text mining process of co-word analysis. Combined with a numerical spatial model simulating the CSA, sustainable and fundamental solutions are put forward. The structure of this paper is organized as follows. Section 2 presents the methodology and designs the SDFT paradigm for risk identification. Section 3 depicts the ST in crowd stampede. Section 4 presents the case study of the Shanghai Stampede Accident based on the proposed approach. Section 5 presents a further discussion. Section 6 provides conclusions and further studies.
2. Methodology
Our approach presented in this section is brief and follows a top-down analysis structure. CLD, a representative ST model, is adopted as the main method conducting the whole process of risk analysis, which focuses on identifying the underlying interrelationships of diversified levels, so as to promote understanding the effects of these situations (Mulej et al., 2004). It is initiated with the level of contributory factors and delves down as warranted by the analysis of the top results. Then, after the construction of the CLD, system analysis of CSA is supported coordinately by a theoretical paradigm and agent-based simulation. The theoretical paradigm is structured through a procedure of co-word analysis where the high-frequency keywords and the interactions between high phases are described. Moreover, agent-based simulation is used to develop a spatial model for simulating the accident. The approach is shown in Figure 1 and can be briefly illustrated as follows.

2.1 Causal loop diagram
CLD provides a map that the causes and effects of the whole system demonstrate cyclically and continuously (Liu et al., 2012). The framework for identifying the interrelationships rather than individual parts of ST is shown in three basic processes – reinforcing feedback, balancing feedback and delays.

Reinforcing loop seeks to strengthen a particular behavior in the continuous cycle (either positive or negative) (Argyris and Senge, 1990; Mella, 2012). A reinforcing loop can amplify the growth or decline of the behavior implied in the nodes. Also, Figure 2 explains a simple example of balancing loop where “actual level” and “improvement efforts” show the opposite
trends. When the gap between actual level and target value becomes larger, possibly more effort is being implemented. In contrast, when the gap declines, the motivation to improve the current situation may gradually disappear and hence the actual level reduces. Delays present a time difference which usually occurs between the execution and the consequences of a certain action (Goh et al., 2010). Ignoring the delays in the causal loops can contribute to the premature estimation of action time. The right side of Figure 2 shows a delay representing the loop from safety behavior to positive consequence, which indicates that the positive consequence is changed before the potential benefit of the actions can be noticed.

A relatively simple systems archetype, named “shifting the burden,” will be introduced in the case study herein. It consists of two main loops, one emphasizing the external symptoms the other emphasizing the underlying traits and causes of the situation (Senge, 2014) (Figure 3). The symptomatic analysis is widely accepted by managers, policymakers and accident analysts, achieving relatively quick results that explain the direct causal link and symptoms of the problem. The latter emphasizes a sustainable and fundamental solution, which takes a delay between implementation and results into account. When symptomatic solutions are selected, there is always an additional route reinforced by “side effect,” which makes it more difficult to arouse the fundamental solution (Fan et al., 2015). Overall, the archetype sums up that symptomatic analysis provides a short-term effective solution and alleviates the pressure of the implementer, but the fundamental solution can solve the long-term problem and concentrate on the underlying loop.

2.2 Agent-based simulation
Agent-based simulation in mass gathering has been widely adopted to analyze group characteristics (Lovreglio et al., 2014) and generally focus on three categories including evacuation simulation of buildings (Tan et al., 2015; Wagner and Agrawal, 2014; Yamamoto, 2013), urban roadways (D’Orazio et al., 2014; Omer and Kaplan, 2017) and crowd behaviors (Vermuyten et al., 2016; Zhang et al., 2016). Compared with other simulation methods, agent-
based systems use a bottom-up modeling where the whole system is controlled and governed by agent settings. By establishing some reaction rules for the virtual agents in special situations, the triggering and development of the CSA can be simulated (Liu and Chen, 2014).

Pathfinder is an agent-based simulation software considering both microscopic and macroscopic perspective for crowd evacuation. A three-dimensional visualized interface is provided through a set of grid design and parameter settings, allowing agents to possess the capabilities of independent decision. According to the surroundings, an agent can automatically determine the direction and route to fulfill the instruction. In this research, Pathfinder is used to combine a large-scale crowd (even millions) with the virtual environment and build a numerical spatial model simulating the Shanghai stampede accident. Unlike other studies that focus on the evacuation to the exit under certain scene, this study programs the agents’ characteristics and routes to achieve randomization and diversification of their behaviors. Then, specific individual behaviors are set to trigger anomalies simulating the occurrence of the Shanghai stampede accident.

2.3 Co-word analysis
The co-word analysis draws upon a consensus that a publication’s keywords constitute a complete description of its content and the inner link between subjects (Ravikumar et al., 2015). It reveals patterns and traits in a specific object or discipline by calculating the association strengths of keywords abstracted from relevant publications and gray literature (Van den Besselaar and Heimeriks, 2006). Thus, the application of co-word analysis on the existing research develops a generic knowledge and basic words in crowd stampede and provides a characteristic paradigm for risk identification.

A comprehensive search is carried out in view of the keywords, such as “crowd accident,” “stampede,” “evacuation” and “crowd flow”. Next, 2,184 related papers and CSAs are extracted from Web of Science database. Then the core keywords are selected through the correlation degree with subjects. Using Citespace software, the co-occurrence matrix is formed and visualized as shown in Figure 4. The size of the nodes represents the frequency of occurrence, and the connection indicates the significance of co-occurrence.

2.4 The theoretical framework of risk identification in crowd stampede
Safety and security precautions of the crowd require not only a whole system model to “see the forest for the trees” but also a systematic perspective to unfold “the trees” (Batat and Prentovic, 2014). A comprehensive paradigm reflecting risk awareness and safety management is formed through the whole fundamental solutions.

Based on the co-word analysis, regardless of the keywords related to research methods, terms and macro vocabulary, the inner bibliometric characteristics are identified by four high-frequency keywords: “design,” “density,” “flow” and “trigger factor” (Figure 4). To understand how crowd stampede is triggered and influenced, we build a so-called SDFT paradigm of systems perspective on risk identification in the CSA based on keywords clustering, where S (surrounding), D (crowd density), F (crowd flow) and T (trigger factor) interact as a synergic system (see Figure 5).

2.4.1 Surrounding. Moussaid et al. (2011) emphasizes that the majority of casualties and property losses during CSAs resulted from inappropriate building design, which points to the initial incomplete proposal. According to Figure 4(a), high-frequency keywords such as “exit choice,” “field,” “park” and “floor” represent the scenarios and fields of CSAs. Holding the subcenters of visualization network, construction defects or structural failures of buildings have become high-frequency keywords in official accident reports and research papers (Abdelghany et al., 2014). For example, in Africa’s 2009 FIFA World Cup qualification, which is
Figure 4. Co-occurrence networks of the high-frequency keywords.

Notes: (a) Surrounding; (b) density; (c) city; and (d) factor.
a series of football tournaments before the World Cup, more than 150 audiences were killed and injured in a serious stampede accident, due to the collapse of a wall within the stadium. A systematic perspective on risk perception needs to be incorporated into the surroundings including exterior and interior environment (Zhang et al., 2007). The exterior risk can be categorized into the consideration of exterior facade, the scenario directly affected the crowd, entrance, and exit, etc. The interior architectural design is more complex mainly including building layout, hazard detection systems, efficient evacuation route, escape sign, etc.

2.4.2 Crowd density. “Density,” as a high-frequency node [Figure 4(b)], has a direct contact with “crowding,” “stress” and “size.” High crowd density has been increasingly focused on as the important factors that occur in CSAs measured by information technologies such as “video surveillance.” Meanwhile, especially in the physical point of view, it is used as an indicator for early warning of the CSA. There are a wealth of theories and empirical evidence concerning that the density of the crowd has an influence on the speed and behavior of individuals, as morphological traits are adjusted in response to environmental conditions (Dupuy, 2005). That is, crowd behavior affects and weakens individual behavior. When crowd density is relatively low, the movement of individuals represents the characteristics of freedom and discreteness. When crowding occurs as the density increases, group behavior plays a leading role forming a kind of potential energy. Moreover, the psychological pressure of individuals reflected in a coherent group is enormous. This situation may promote the emergence of group psychology characterization, such as herd mentality. Individual perception, judgment and knowledge show consistent with public opinion or the majority of people. Panic and anomaly are more likely to spread causing the CSA (Dupuy, 2005; Khalil and Boulding, 1996).

Meanwhile, crowd experiments present that high density of the stationary crowd for just a moment can increase the stability of crowd structure rather than risks (Zhong Yao et al., 2016). Only, taking the duration into account, changes in the factors of the crowd will yield the opposite results. The pilgrimages to Mecca witness serious crowd disasters from 1994 to 2016, the highest density of which can be as high as 10 people/m² (p/m²) in some main areas (Alnabulsi and Drury, 2014).

2.4.3 Crowd flow. Crowd flow represents the group dynamics which holds the center of visualization networks as shown in Figure 4(c). It focuses on the study of how, where and when the crowd is centralized and how it transforms (Liang et al., 2014). The combined
effects of factors such as “scene,” “motion,” “boundary” and “behavior” intertwined through the core words may cause serious consequences due to the abnormal movements. According to the systems theory, the whole crowd possesses greater vulnerability with increasing speed. Taking time and space into account, flow rate, as another important indicator, indicates the number of people passing through a region per unit of time (Dai et al., 2013). Considering crowd flow arising from the above-mentioned indicators, the specific crowds are classified in connection with bottlenecks (gathering to one point), fountainhead (radiating from one point), lane formation (relative flow), ring (spiral flow) and blocking (gathering and bouncing off of each other in random directions), which indicate the potential threats in the crowd (Solmaz et al., 2012).

2.4.4 Trigger factor. Huang (2003) states the influencing factors of the CSA can be divided into pre-trigger factors and post-trigger factors. The former can directly converse the critical condition, and the latter may lead to sustained chain reactions. Meanwhile, the trigger factors of the CSA are likely to vary from accident to accident. Keywords related to the traits and causes of the CSA are abstracted from 147 serious accidents from 2000 to 2017 as shown in Figure 4(d). Keywords with the highest frequency are “stampede” and “crowding,” occupying the center of the visual network. Four major themes are identified which establish a strong coexistence relationship with core keywords. Human factors experience the largest proportion (e.g. “rumor,” “panic,” “snatching” and “violence”) and refer to the individual improper behaviors. Event factors referring to some large-scale activities may hide serious security risks such as “celebration,” “religious activities” and “sporting events”. Meanwhile, CSAs are also attributed to some management factors with the lack of risk identification and natural factors.

3. ST in crowd stampede
The occurrence of CSAs always lies in intertwined individual behaviors and the underlying surroundings, most of which seem preventable but cannot be recognized as a simple conduction mechanism (Underwood and Waterson, 2014). They are always involved in a complex system, comprising a large number of interconnected elements such as pedestrians, surroundings, officials, regulations, etc. The crowd system, mainly with a view to ST, is identified as four properties: entirety, hierarchy, dynamic and mutation.

Consistent with the systems theory, the whole is not equal to its parts taken together, but greater than it (Lovreglio et al., 2014; Mella, 2017). When people become anonymous within the crowd, they tend to lose their identities, which means the normal value, standard and the ability of independent thinking are forgotten. System properties that its constituent elements do not obtain are formed. Thus, the influence of individuals on the crowd system can be multiplied by elements, links, structures, functions and the environment, which arousing a holistic effect integrating various components.

The crowd system consists of a certain hierarchical structure, in which the lower-level elements belong to the high-level organic components. As Leveson (2011) points out, the first part of the stampede lies an individual level – for example, a pedestrian. Structural and functional connections of individual components are indicated to form a unit at the second level, increasing the complexity and conductivity of actions. Movements and collisions of units form the subsystem at the third level such as flows and bottlenecks. Involved in the environment, subsystems are integrated to form the entire system at the fourth level. Structural failures usually appear at the first two levels and suddenly break the balance of the crowd system.

Due to the complex internal and external connections, the crowd system is continuously experiencing transformations between disorder and order, exhibiting dynamic behaviors as the components evolve over time. The interaction between system elements, especially the
behaviors of individuals, constitutes the fundamental driving force of system dynamics and a trade-off among the various components leads to the dynamic evolution of the whole system.

Separated elements implicated in CSAs often represent normal values and show little indication of impending accidents among the crowd system. The systems perspective argues that the risk often hides in the conventional environments and usual debugging (Leveson, 2015). In the crowd system, once a factor suddenly dominates or obtains the overwhelming power, a systematic variation occurs, resulting in an abnormal performance. The CSA is regarded as a unique anomaly arousing from the susceptible and frangible system.

4. Case study
The case study herein describes the 2014 Shanghai stampede that occurs in New Year’s Eve countdown activities. It presents superficial and fundamental causal loops that discuss how the underlying systemic interactions form and continuously recognize the key risks of the CSA.

4.1 Brief description of “12·31” stampede in the bund
Huangpu District Government (HDG), Huangpu Tourism Bureau (HTB) and Shanghai Television (ST) have organized New Year’s Eve countdown activities three times in the Shanghai Bund since 2011. In view of security and other certain uncontrollable factors, the event place is changed to the Bund source in 2014.

On December 31, 2014, at 08:00 p.m., a large number of public tourists flocked to the viewing platform of the Bund, a long and high terrace along the Huangpu River, showing the gradual trend of gathering. At 10:37 p.m., the one-way traffic warning signs of the stair in the southeast corner of Chen Yi Square were broken by the crowd. The police tried to maintain order, but regardless of command, the crowd flow poured onto the viewing platform in the wrong direction. From 11:23 p.m. to 11:33 p.m., the opposite flows impacted, continuously forming a stalemate in the middle of the stair. At 11:35 p.m., the downward pressure of the crowd suddenly increased. People at the bottom lost their balance and fell down, triggering a chain reaction of pushing and stacking, then stampede occurred. Polices and public tourists tried to pull out the people on the ground. But the injured were still squeezed by the top, then the second accidents continued to occur. Lasting for about 3 min, the crowd above the stair began to retreat under the command of polices. As the density of personnel gradually reduced, the injured were moved to the ground for rescue. In general, 36 people were killed and 49 more were injured in this tragedy.

4.2 Spatial model and parameter setting for the bund
The bund is a waterfront area which runs along the bank of the Huangpu River. The stampede occurred near the famous attraction viewing platform with three ground floors. Its base floor is Chen Yi Square with 2,858 m². The main low platform selected as simulation scene is 15,293 m² and the higher one is 4,428 m². The main stairs include two wide stairs near the high viewing platform and two narrow ones near Chen Yi Square. Based on actual measurements, the basic blocks are provided by Pathfinder and a spatial model for the Bund is shown in Figure 6.

Considering the fluctuation of walking speed, the speed of pedestrians is assumed to follow the normal distribution. According to Liang et al. (2014), the walking speed in Bund varies from 0.8 to 1.1 m/s and the average value is 0.95 m/s. Meanwhile, an early investigation is conducted to measure the human body data of Shanghai as the reference for agents such as shoulder width. In view of the accident report, 112,725 people are randomly placed in the spatial model. Their behavior is set to randomly visit the main attractions and
evacuate with the steering approach. Then a small group of people is programmed to arrive at the location of the stampede to block the flow with the trigger action at 300-400 s and then evacuate with other agents. We mainly focus on the characteristics of the crowd before and after the CSA, without considering the overall time of evacuation.

4.3 Analysis of the “12·31” accident using ST approach

According to the task division and accident sequence, the stampede can be regarded as a two-stage problem. The first one is why the protocol is designed with defects resulting of insufficient policies, unreasonable arrangement and improper notice, and the second question is why the response to the abnormal crowd gathering is inappropriate. Based on the CLD, the Shanghai Stampede is placed in a two-dimensional coordinate system (see in Figure 7). The horizontal axis depicts the time index and division of the diagram into two independent diagrams, representing the stages of the activity. The vertical axis includes two solution loops separated by the main questions raised above. The arrows in two symptomatic balancing loops are drawn in black, and the arrows in two fundamental solution loops are painted blue. The side effects are emphasized with red lines.

Form the causality loops of two stages and find the symptomatic solutions. Dissect the fundamental solutions based on a crowd simulation and find the side effects.

4.3.1 Analysis of the symptomatic solutions of “12·31” accident. Before the activity, HDG is responsible for leading and coordinating the multiple departments, and HTB is appointed as the main contractor to develop the activity program. Due to the urgency of organizing the activity, both of them show passive safety attitude and promote negative security awareness in its subordinate departments. Huangpu Public Security Bureau (HPSB) and Huangpu Municipal Commission (HMC) do not conduct security assessment for the possible locations of crowding. Meanwhile, the notice and news posted by HTB and ST are neither clear nor timely, which misleads the public. The passive safety attitudes by these departments produce a process of linear conduction and eventually lead to the defective risk protocol (see the left side of Figure 7).

Turning now specifically to the site, HDG is responsible for the coordination of multi administrative departments, but the 24-h duty system is not strictly enforced and no additional staff are arranged near the viewing platform. HPSB and HMC are the main departments of site management, especially the former, but make a defective analysis and respond to the monitoring data. Also, the security forces deployed near the Bund are insufficient to deal with emergencies. The improper responses of the departments are just passive reactions shown on the right side of the symptomatic circle (see the right side of Figure 7).
Table I.
Description of the symbols in Figure 7

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure of organizing events</td>
<td>Variable</td>
<td>It is a variable that can be defined as the cause, consequence, effect, and solution of the CSA</td>
</tr>
<tr>
<td>Arrow</td>
<td>Black arrow with a +/- sign: defines the same/opposite movement direction between the variables in symptomatic solution loop Blue arrow with a +/- sign: defines the same/opposite movement direction between the variables in fundamental solution loop Red arrow with a +/- sign: defines the same/opposite movement direction between the variables of side effects</td>
<td></td>
</tr>
<tr>
<td>Balancing loop</td>
<td>Define a symptomatic solution loop (black)/ fundamental solution loop (blue) which attempts to change the current state to the desired state (goal or objective)</td>
<td></td>
</tr>
<tr>
<td>Reinforcing loop</td>
<td>Define a side effect in which one action produces a growth or decline which influences more of the same action (effect or solution)</td>
<td></td>
</tr>
<tr>
<td>Delay</td>
<td>Define a dynamic response in the effect of a side action on a fundamental solution</td>
<td></td>
</tr>
</tbody>
</table>
The organization form used by government-led activities subordinates to a host-driven style. However, public security issues are only considered by the government, the contractor works on its assignment by following the command of higher authorities. Although safety attitude is accepted, only HPSB and HMC are really responsible for the activity safety. There is no safety awareness integrated into the whole system. None of these departments performs according to effective programs when emergencies occur near the Bund.

This tragedy awakes the departments to realize the problem of “design of defective risk protocol” and “improper response to emergencies.” The symptomatic solution, named ‘fly-fix-fly approach’ (Fan et al., 2015), is proposed to quickly resolve the symptomatic problems, such as increasing the risk awareness, reporting the situation of the scene frequently and strengthening the management of crowd flow. The chains of causality and the balancing feedbacks are shown in Figure 7.

4.3.2 Analysis of the fundamental solutions of “12·31” accident. There will no longer be the adequate trial and error opportunities to improve all the potential defects (Liu et al., 2012). Even after the quick fix, they know how to respond to the Bund stampede correctly, but some other unexpected, different emergencies may occur. If systems perspective had been used, the risk protocol of CSA would have been encouraged by HDG and other departments.

4.3.2.1 Self-regulation mechanism in different departments. The concept of “self-regulation mechanism” should be informed to the multiple departments, adopting prospective risk perception to cope with problems. Then each department will show primary responsibility for reducing the risk of notes. Regulatory authorities will also contemplate the improvement of the regulatory system, but it needs more time to be understood and tested. Thus, there is a time delay between official supervision and advanced consequence. The symptomatic solution is a quick way to solve the problem, to some extent, excessive use of which will reduce the force of ST (shown in R1.1 in Figure 7). There is also the possibility of deterioration for potential problems without any intervention.

4.3.2.2 Systematic perspective on the crowd risk – SDFT paradigm. The key risks related to the crowd gathering can be combined effectively in the process of “SDFT diagram” through a crowd simulation, which is treated as a fundamental solution in balancing loop B1.4 and B2.6 (Figure 7).

4.3.2.2.1 Surrounding. Taking into account the previously explained details, the Bund is an open area with a strip structure from four main roads. The crowd will pour into a strip structure (see Figure 6) and undoubtedly return from the original route. Only two wide (12 m) and two narrow stairs (6 m) are insufficient for the pedestrians to board the viewing platform, and there is no one-way facility that is placed nearby to promote faster evacuation. Then, the safety capacity can be roughly calculated by the area size of the viewing platform which is about 20,000 m². Crossroads, main attractions and stairs are the high-risk locations.

4.3.2.2.2 Density. Governments should be undertaking initiatives to reduce the whole risk. These initiatives need to focus on, for the most part, estimating the density before the activity according to the actual observation and highlighting main places where the crowd will gather. Moreover, concentration on densities associated with monitoring and analyzing could overlook important indicators that emerge from the interactions among the crowd.

Figure 8 illustrates a continuous change in density of the Stair C during the simulation, which is much higher than the rest parts and reaches an average of 6-7 p/m². With continuous gathering, densities of the crowd present a dynamic balance after the impact of a swift flow. Just like a “pulse,” the deep color areas (with high density) are constantly fluctuating among the intersection of the structure from 200 to 300 s. The trigger action is executed at point P at 300 s. Then, the “pulse” gradually weakens. After a short delay, the deep color begins to expand in the P-centric area at about 323 s, which reaches its peak
engulfing other high-density centers at 350 s. It lasts about 30 s until the trigger action ends. Then, the trigger action stops at 400 s. The density near P gradually decreases, the speed of which is obviously slower than the increase. After 500 s, the color of the crowd image gradually tends to be stable, but the density near P is significantly higher than the initial value. Dynamic pulse continues until the crowd gradually evacuates.

It indicates a diffusion effect that energies of the crowd can be stored and transferred between subsystems. The “pulse” may be attributed to the collisions of agents in the crowd trying to transfer excess energy. The presence of this phenomenon, or disorder, can make systems unpredictable, as high-density points have already begun to appear before the stampede. Then, it undergoes a short delay before the local density grows rapidly and begin to spread, mainly because the agents forced to change the directions block the curved paths. The sudden trigger action for the mass gathering which is set in the simulation can thus result in a new dynamic balance with higher local average density.

4.3.2.2.3 Crowd flow. Identifying the special flow of the crowd should be considered as another indicator for the stampede when designing risk protocol, such as recognizing the direction of flow at each major road or intersection and determining the impacts of different flow types (Peizhong et al., 2011). In particular, the simulation results state the accurate trends in flow patterns.

Figure 9 presents the complex flows involved in the dynamic balance before the stampede. “Ring” flows appear at the bottom of Stair C and form a kind of inward pressure flocking to the stair. The crowd on the square is blocked by the arch structure. “Bottleneck” flows, curved gathering lines, form and increase the forward pressure of the crowd. In this situation, the opposite flows are impacting at the middle and top of Stair C. Then it shows an agglomeration effect that all the energies are converged at the junction of stair due to the “Lane Formation.” Thus, three forms of flow concentrate the whole pressure to one point and extremely increase the instability of the crowd system.

Specifically, Figure 10 illustrates a deep observation on the flow rate of stair C. An empty stair is provided to form a collision from two directions, so the flow rate presents a sudden growth and decline before 50 s, then achieves a dynamic fluctuating with the relative balance between 200 and 300 s, which vividly specifies the “pulse.” With the trigger action in 300 s, the flow rates of the top and bottom gradually decrease and the peak values are significantly lower than before. Then the bottom crowd is suddenly blocked when the value becomes 0 at 350 s. The flow rate of the top fluctuates at a lower level. It indicates that the blocking has a greater impact on the flow of the same direction. After the trigger action stops, the valves suddenly experience a dynamic growth and rapid decline. The abnormal agents return to normal actions and provide unobstructed routes for evacuation, but sudden movements cause local chaos. Then the crowd blocks for nearly 20 s and reaches a new dynamic balance, the flow rate of which is significantly lower than the original after 500 seconds.

Figure 8. Continuous changes in density of the stair C.
4.3.2.2.4 Trigger factor. The possible emergencies should be evaluated and considered from four aspects before and on the site of the activity. According to the accident report, the main trigger factors can be identified as human factors (falling down, panic, squeezing), event factor (celebration) and management factors (misconduct of risk identification, inadequate preparation of the risk protocol, insufficient ability of cite control). In this simulation, the trigger action is programmed that a group people instantly block the flow near Point P.

As the systems consciousness is difficult to set up and follow, there is a delay and selective avoidance between the implement of “fly-fix-fly approach” and the underlying solutions, causing the side effect “reactive safety perspective” (see in R².1 in Figure 7). This will make the whole system gradual worse.
4.3.2.3 Multi-dimensional system analysis. Emergency capabilities vary with the individual constitution and sensorial cues received from the surroundings. However, the trigger factor often occurs suddenly and lasts for a short time. It is difficult for managers to capture the short uncertainty, but possible to make effective and accurate predictions of upcoming accidents through monitoring the critical values of indicators. The multi-dimensional analysis including physical, psychological and physiological aspects is formed in site control.

From a physical point of view, individual behavior and group behavior need to be recognized and analyzed. The surveillance videos show that some individuals cannot stand the high pressure from the direct environment. Specifically, subtle behaviors are captured related to individual instability such as stretching out the arm, tilting the main body and pointing toes (Mawson, 2005). They lean back and forth affected by the sudden power, resulting from the crowd waves. Also, special behaviors such as self-protection, pulling and escaping appear near the location.

Psychological indicators are difficult to obtain from the CSAs. But emotions representing psychological characteristics can be identified by the face recognition system, thermal sensors (Ali and Shah, 2007), etc. Some hidden omens such as anger (squeezed by around), panic (losing or falling), puzzle (swing back and forth) and suffering (beyond the tolerable thresholds) are clearly achieved by the monitoring system.

Furthermore, the incomplete physiological values of the CSA are only indirectly acquired by some researchers or experiments. The heat values near the location of the stampede show a deeper color than the rest city, which means the body temperature is higher than the normal due to the high density (Zhou et al., 2016a). Similarly, the heart rate shows a significant increase due to the psychological pressure and anxious feelings. The same opinions are tested by crowd experiments and simulations (Zhong Yao et al., 2016). However, there is also a time delay between perception and physiological response of individuals.

5. Discussion
As the interactive effects present complexity and variability in the two causal loops, accidents resulting from the structural disorders among components show more instability (Underwood and Waterson, 2013). The ambiguous division of rights and obligations in government-led activities usually has a tendency of shirking responsibility and following procedures (Adamatzky, 2005). Commands are generally executed from superiors and relevant thinking is rarely spontaneously conducted. Thus, the “fly-fix-fly approach” only relieves the superficial symptoms but does not touch the root causes.

“SDFT paradigm” dominates the fundamental solutions of the two stages. The thinking mode of systems perspective regards the CSA may experience an interactive process of accumulation, trigger, delay, break and diffusion of risk factors within the system. Three special flows “Bottleneck,” “Ring” and “Lane” form a chain reaction of energy transfer and accumulation, which guides the distal pressure to concentrate on the stair. After the trigger action or factor, there is a certain inertia reaction within the system. Thus, short delays appear both in the continues changes of density and crowd flow, resulting in a time difference between triggering and reaching the critical value. Then, the pressure is instantaneously concentrated and accumulated as the flow rates tend to zero.

Particularly, a linkage effect among the multidimensional characters of individuals and the crowd system accelerates the deterioration of risks and causes the tragedy. A short delay also occurs when individuals unconsciously percept the change of surroundings and make the reaction, especially for physiological characterization. The individual symptoms coincidentally wait for the system delay and match the peak value of the crowd. The indicators of a region suddenly exceed their thresholds, then the integrity and stability of the
system are broken as the mutation of conditions. After the trigger action ends, the system reaches a new dynamic balance with high local density.

According to the “shifting the burden” archetype, the upper solutions result of side effects represents enhanced features, which leads to a phenomenon that gradually deviates from the main causes. A “dangle,” known as policies and factors, usually change the nature of the reinforcing type from exponential growth to exponential decline. The self-regulation mechanism limited by safety systems is the dangle of the system which determines the capability of a systems perspective. Self-regulatory capacities of multi administrative departments have a direct impact on the emergence of systems perspectives, that is, the use of SDFT paradigm to propose sustainable solutions. Meanwhile, at the second stage, the SDFT paradigm is extended as a theoretical framework to provide thought path and data support for multi-dimensional system analysis, mainly in the physical level. The CLD for the stampede can be regarded as the whole system sequentially. Proactive factors such as the aspects of policy formulation and the architectural program should also be considered to avoid accidents from the root causes.

Moreover, the proposed approach can be used not only for the analysis of the CSAs but also for general accidents. According to the schematic diagram (Figure 1), accidents can be depicted step by step. Processing loops present the contributory factors and outline the non-linear relationships. By means of text mining and co-word analysis, the accident-related paradigm of risk recognition can be created to assist in exploring the fundamental solutions. At the same time, appropriate simulation methods can be applied for the reproduction of accident’s scene. All in all, this approach provides a common path for multi administrative departments and effectively raises a sustainable systems solution.

6. Conclusion
ST, known as “seeing the forest for the trees,” provides complex routes to have an insight of the unidentified contributory factors. Application of ST contributes to the early prevention and control of emergencies. The Shanghai Stampede is regarded as one of the most serious crowd disasters causing tragic consequence in the past 30 years in China. The “shifting the burden” archetype is used in this study to identify the symptomatic and fundamental solutions of the CSA and reveal the cycle accumulation of different levels.

This research presents a top-down analysis approach with ST perspective which can be offered to policymakers for crowd stampede risk protocol design and synergetic emergency control. Co-word analysis is adopted to extract the keywords from current research and forms the SDFT paradigm of systematic perspective on the risk of stampedes. Then, based on the main components related to defective behaviors, chains of causality are formed. The feedback loop shows that the “fly-fix-fly approach” holds the potential power to be chosen preferentially, but only is a superficial solution. In contrast, the fundamental solutions are formed to recognize the stampede risk with an enduring way. Stampedes may experience a chain reaction of energy transfer and a linkage effect among the multidimensional characters of individuals and the crowd system. However, there exists delay of the result of effect from the deep-level measure, which will cause some unexpected side effects. Meanwhile, the fundamental causal loop presents the ST mode and chain causality from the supervision to implementation. “Self-regulation mechanism,” as the unique dangle, determines the source of fundamental solutions.

However, a systematic analysis is conducted after accidents but not before in this study. Some data that we mention in the “multi-dimensional system analysis” cannot be achieved, and the critical values individuals may endure are unintelligible. Then the authors believe that this study offers some system insights to accident analysis, and the further studies need to focus on measuring the thresholds based on crowd simulations and experiments.
References


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Abstract

Purpose – The purpose of this study is to analyze the impacts of different policies to address the water supply crisis experienced by the metropolitan region of Sao Paulo during 2013 to 2015 and evaluate the resilience of its water supply system for the coming years.

Design/methodology/approach – The methodology used in this study is based on the system dynamics simulation paradigm, combined with empirical data obtained from the regional water authority.

Findings – The results from the simulations suggest that the first layer of sustainability of the water supply in the region strongly depends on how the system’s operator responds to crises, in particular how it balances policies acting on the supply and demand for the resource.

Practical implications – Severe water crises typically make salient the perception that water is a finite and public resource. Long-term, sustainable management of the system requires a paradigm shift from
widespread, old-fashioned beliefs that water is an infinite resource. It also requires active management to increase the system’s preparedness to withstand events caused by climate change.

**Originality/value** — This study contributes to the system dynamics and water resource management literature by presenting an integrative model to evaluate the resilience of a particular water supply system. Although there are previous studies on this subject, the present one focuses on the role that the water authority plays in a crisis and especially on a specific combination of policies to address an episode of crisis in a system unprepared for it.

**Keywords**  
System dynamics, Metropolitan region of São Paulo, Water supply crisis

**Paper type**  
Research paper

1. **Introduction**

In a famous TED talk, behavioral economist Dan Ariely (2011) claims that if we had to design a problem to maximize human apathy, then this problem would be climate change. It is perceived as an abstract event in the future; we do not see people suffering from it; there is no meaningful feedback on its evolution over time; it will affect other people first; and finally, anything that we as individuals could do to prevent or mitigate it is a tiny drop in the bucket.

However, climate change, as abstract as the common framing goes, may affect people’s lives in very concrete ways. In fact, recent droughts in several parts of the world may be one of the first concrete symptoms of human-induced climate change. According to the research community, it is very likely that there has been an increase in the number of warm days and nights in recent years and there is high confidence that climate change can affect water management systems in significant ways (IPCC – Intergovernmental Panel on Climate Change, 2012). Not only have droughts disrupted water supply systems in regions where water scarcity is frequent, such as California and Texas in the USA, but they also started to affect places that never suffered from severe water scarcity before, such as the metropolitan region of São Paulo (MRSP), in Brazil, which experienced an unprecedented crisis in the years 2013-2015. Furthermore, there is the expectation that widespread water stress will affect global economic growth in the coming decades (Water Resources Group, 2009).

Hence, the design of public policies to address this multifaceted threat will increasingly depend on models capable of dealing with extreme scenarios.

This study contributes to this effort by presenting a simulation model developed to study the water system in the metropolitan region of São Paulo (MRSP). According to EMPLASA (2017), the MRSP comprehends 39 municipalities and represents a strategic Brazilian region from an economic point of view, with more than 21 million inhabitants, which corresponds to 47 per cent of the São Paulo state population and 10 per cent of the Brazilian population. Far from being in equilibrium, its population has been growing at an annual geometric rate of 1.28 per cent (between 2010 and 2016). The region is responsible for generating 18 per cent of Brazilian gross domestic product (GDP) and 55 per cent of the São Paulo state’s GDP.

During the period between 2013 and 2015, the MRSP experienced the most severe crisis in its water supply system since the development of its structure in the mid-1930s. Reservoirs’ levels dropped to very low volumes, and one of them – the Cantareira subsystem – virtually reached the brink of collapse. Previous periods of drought, such as in 1953/1954 and 2003, while less severe, had alerted the system’s managers to devise policies such as maximum extraction rates to mitigate potential risks in the system. Nonetheless, the crisis experienced in 2013/2015 made clear to external observers that the bodies of public administration in São Paulo state never expected very extreme scenarios – in particular, scenarios capable of pushing the whole system to its limits.
The severity of the situation derived from a steep decline of water flows into the system’s reservoirs (Figure 1). This reduction was caused by low levels of rainfall, which the Brazilian National Water Agency (2014) attributes to one of the worst drought periods registered in the country.

According to the National Water Agency (2014), the southeast Brazilian region, where the MRSP is located, suffered a significant reduction in its rainfall index when compared to historical records (available since 1930).

However, the causes of the problem cannot be reduced only to an episodic fall in rainfall rates. The low resilience of the system in response to an unexpected perturbation also came from other important elements. First, the system was never managed to incentivize rational consumption of water, on the contrary. Second, for economic and regulatory reasons, rates of leakage in the system, which represented approximately 31.8 per cent of the distributed volume in 2016 (SABESP, 2016), never inspired much concern from the operators. From a broader perspective, policies regarding tariffs never incentivized levels of investment necessary to prepare the system for more rational and ecologically sustainable uses of water. Treatment of sewage, for instance, is notoriously deficient both in the MRSP and in Brazil as general. Other aspects that could increase the system’s resilience, such as its adaptability, have not been managed properly (see EPA – USA Environmental Protection Agency, 2015, for a comprehensive review of resilience in water systems). In sum, the dominant logic in the system has been commercial exploration without further consideration for its long-term resilience against unexpected shocks from nature.

The Brazilian National Water Agency is the federal public administration entity responsible for defining the limits for water exploitation and providing the grants that permit SABESP (Basic Sanitation Company of the State of São Paulo) to explore the water sources to fulfill the demand in the MRSP. SABESP is a company controlled by the government of São Paulo state. It is responsible for managing the system’s main reservoirs, the water treatment plants, the distribution systems, as well as the subsystems of sewage collection, treatment and disposal. The main reservoirs in the system are named Cantareira, Alto Tietê, Guarapiranga, Cotia, Rio Grande and Rio Claro.

![Figure 1. Sum of water inflow to all the system’s reservoirs (m^3/s)](source: Adapted from SABESP (2017b))
The whole system managed by SABESP is known as Metropolitan Integrated System (SIM – “Sistema Integrado Metropolitano” in Portuguese). As shown in Figure 2, in February 2014 (before the peak of the crisis), the SIM operated with a rate of water supply close to 72 m$^3$/s, which is almost its maximum output operational capacity. Just over a year later, in March 2015, the system was operating under a steep reduction in water supply, providing approximately 51 m$^3$/s.

This sudden reduction in outflow was mainly a consequence of governmental policies aimed at reducing consumption during the crisis. The policies combined financial incentives and fines, awareness campaigns (delayed because of political reasons considering the proximity of elections) and controversial measures such as a decrease in water pressure and interruptions in supply. Experts claimed that reducing pressure in the distribution system increased the odds of water contamination and leakage, but the policy was maintained. In addition, the interruption in the supply of water led to widespread complaining among the population. As several policies went into effect simultaneously, it is not possible yet to discern their separate effects on the reduced consumption of water. In other words, that reduction may have responded to an unknown (so far) combination of changes in public attitudes and restrictions imposed by SABESP on the distribution of the resource.

Figure 3 presents the aggregated level of all water reservoirs that compose the system. Oscillations are typically associated with the rainy (between January and March) and the dry (between July and September) seasons. As the figure illustrates, the lowest volumes in the series occurred in 2003 and then in 2014. In the latter year, SABESP had even to resort to using the so-called technical reserves (water situated below the levels of pumps), pushing the measured operational levels below zero.

Despite the significant drop in the system’s water levels during the crisis, the reservoirs were partially recomposed in the following years. According to SABESP (2017a), by the end of October 2017, the water levels recovered to approximately 50.1 per cent of their full capacity. However, the scenario still inspires caution as the time of writing (2018). Scarcity looms on the horizon, especially if the system continues to be managed without a sharp focus on its long-term sustainability.

Gaviolli (2013) argues that growth in population and economy naturally drives increased water demand, producing conflicting tensions between urban and economic expansion, on the one hand, and water and environmental security, on the other hand. The former requires
an increase in water supply, including the search for increasingly distant sources, while the latter element restrains the exploitation of a natural and scarce resource. These tensions or the paradox of economic growth versus preservation of natural resources may represent new challenges to a country (Brazil) accustomed to abundant sources of water.

Hence, the main goal of this study is to address the following research question: how resilient will the MRSP system be in the face of possible changes in the averages of annual rainfall? If rainfall averages become more dispersed and extreme than historical trends, then scenarios of crises can become more frequent, testing the resilience of the system. The study intends to understand the extent to which the system can withstand extreme conditions in the future.

Using the system dynamics method (see below), we develop a model to simulate and assess potential scenarios for the water supply system in the MRSP. We are especially interested in the evaluation of the long-term impact of interventions already tried (such as awareness campaigns, restriction in supply, financial incentives and penalties and use of emergency reserves) and others under consideration, in particular policies to decrease the natural demand for water among the population.

This study is organized into five sections. Section 2 presents a brief review of relevant cases of water crises in the world and a literature review of previous papers that used the system dynamics approach to similar cases. Section 3 describes the method and the strategy adopted in this study. Section 4 proceeds to discuss the model, its simulation runs and the analysis of scenarios. Finally, Section 5 presents the conclusion, limitations of the current study and suggestions for future research.

2. Research background
This section of the study offers an overview of the literature related to water crises in different areas of the world and previous studies that applied system dynamics to investigate the challenges of water supply management.

2.1 Water crises in other areas of the world
Mekonnen and Hoekstra (2016) found that two-thirds of the global population lives under conditions of water scarcity at least one month per year and half a billion face severe water...
scarcity during entire years. Indeed, anthropogenic climate change may lead to more variability in surface water flows in several parts of the world, as well as increased competition among countries and economic sectors (Döll et al., 2015).

However, what has been capturing the media’s attention in developed countries are the cases of intense droughts in important regions and cities and the corresponding policies to curb demand and increase the supply of water. In Europe, for instance, the city of Rome faced a water supply crisis in the summer of 2017 because of a long spell of dry climate and the lack of preparedness from the city’s public management system (Horowitz, 2017). The same problem has been plaguing other Italian cities and other areas in Europe.

Analyzing data from 900 years of Mediterranean drought variability, Cook et al. (2016) estimated that the 15 years (1998-2012) recent drought in the Levante is very probably the driest in the record, offering support for the hypothesis of anthropogenic climate change. Not only have recent decades witnessed a marked decrease in the runoff and water yield of Mediterranean rivers, but also, in the case of the Spanish Pyrenees, there is an expectation of reduction in annual streamflows by almost 30 per cent in the coming decades (López-Moreno et al., 2014). Moreover, there are initial signs of geopolitical dispute between Spain and Portugal over the waters from the famous Tagus/Tejo river – waters that tend to be increasingly scarce (Burgen, 2017).

Recently, an upcoming crisis captured the attention of the media worldwide when Cape Town, in South Africa, announced its water supply system was heading to complete dryness in few months, after a three-year drought. Famous for its sustainable practices, the city’s system has relied entirely on dams and, therefore, on rainfall (Onishi and Sengupta, 2018).

Three additional cases from areas known for their water vulnerability are cited here: California, TX and Melbourne.

In USA, the state of California faced five consecutive years of drought that ended only in 2017 when large storms made it the second wettest year in the record (California Department of Water Resources, 2017a). Also, the summer of 2017 was the warmest on record for many parts of the state, following a trend of warmer temperatures that began in the 1980s (California Department of Water Resources, 2017b). Among the measures adopted by the state to curb water consumption, it banned wasteful practices such as hosing off sidewalks, and it instituted permanent monthly water use reporting. The reduction in yearly consumption amounted to 23.9 per cent (Government of California, 2016).

Still in the USA, TX is another state often afflicted by droughts. It also illustrates the importance of considering not only levels of reservoirs – which are only buffers or providers of slack in the system – but also the rates of water inflow and outflow. In practice, the inflow of water determines the ultimate resilience of the system. In the recent drought, starting in 2010, the rate of water inflow in Texas was even worse than the famous, severe 10-years drought that affected the state in the 1950s (Austin Water, 2015). The state also adopted restrictions on consumption as part of its strategy to reduce demand and decreases in the use of water have reached California’s levels.

In Australia, following the so-called Millennium Drought (started in 1997) and recognizing threats such as continuous population growth and climate change, the city of Melbourne adopted several policies to respond to unpredictable weather extremes (Ferguson et al., 2013). It changed its water system towards a hybrid of centralized and decentralized infrastructure, adopting flexible, modular elements to foster rapid adaptation (for instance, locally managed storm water harvesting). In addition, Melbourne invested in a controversial desalination plant to use water from the ocean, which came into operation in 2017 (Melbourne Water, 2017). Melbourne epitomizes what may become common practice in
other parts of the world if stronger water crises develop in the coming decades. Extreme measures such as using water from the ocean (a costly operation) or bringing water from very long distances (increasing the risks for conflict over the resource) may increasingly comprise a repertoire of last resort measures in water management systems.

2.2 System dynamics literature

A brief review on the system dynamics literature revealed some common threads: the role of pollutants in degrading water systems, different degrees of systems’ resilience to relentless increases in demand, the importance of infrastructure and the difficulty in communicating the complexity of the problem and realigning the conflicting interests of distinct stakeholders.

Treating pollution as the main threat to water supply and emphasizing the trade-off between environmental protection and economic development, Guo et al. (2001) propose a model to analyze the effects of policies to create a sustainable water system in one of the major water systems in China. In the same vein, Simonovic (2002) discusses a model for the future of water supply in the world, identifying water pollution as the major problem in the coming decades.

Xu et al. (2002) use an object-oriented system dynamics approach to evaluate the sustainability of the Yellow River basin in China against pressures from population, agricultural and industrial growth, as well in response to climate change. Pressures on demand may also come from deep-rooted lax attitudes towards water use. For instance, Stave (2003) developed a model to clarify the problem of water scarcity in Las Vegas (USA), identifying what seemed a counterintuitive solution – the need to curb outdoor residential water use. Also, her work illustrates how system dynamics modeling can help in aligning the interest of different stakeholders, which may have different levels of technical expertise. System dynamics can be useful to shift the discussion from the usual blaming paradigm to how the water system works and why it responds to policy changes as it does.

Similarly, Tidwell et al. (2004) developed a model to simulate alternative scenarios for the Rio Grande basin in New Mexico (USA), which is a water supply system with strong variability in its inflows and competing demands from different subsystems. The model was used to engage a diverse set of stakeholders, who had access to a simulation interface. One of the key lessons from the work was the gain in public’s comprehension regarding the complex interdependences in the system. This helped in facilitating dialogue among social actors who previously would have held simplistic mental models about the problem. Other similar cooperative modelling approaches are described in Pierce et al. (2006) and Tidwell and Van Den Brink (2008).

Winz, Brierley and Trowsdale (2009) emphasize the advantages of using system dynamics modeling coupled with participatory procedures to address the complex problem of water management, which involves scarce and contested resources, and multiple stakeholders. However, dealing with conflicting viewpoints may be challenging. To this end, Beall et al. (2011) describe a participatory modeling process that proved to change perceptions of key social actors in the Palouse Basin (USA) regarding the sustainability of that water system, in particular in a business-as-usual scenario. In their study, a stock and flow model helped to estimate the impacts of growth in demand for water and the effects of conservation policies.

Sánchez-Román et al. (2009) describe worrying scenarios for the Piracicaba–Capivari–Jundiaí basin in Brazil, suggesting that the coming decades will see the deterioration in its sustainability, stronger pressures in water demand – eliminating the current slack in supply – and decreasing consumption from residences.
Adopting a different approach and considering the management of a municipal water utility in Canada and its wastewater network, Rehan et al. (2011) argue in favor of proactively rehabilitating the physical infrastructure, which may allow the water supply system to achieve financial sustainability without having to push higher fees into consumers.

Mirchi et al. (2012) advocate the use of different tools from the system dynamics’ repertoire – causal loop and high-level stock and flow diagrams, system archetypes and reference modes – for holistic conceptualization of problems regarding water supply. They stress the need to avoid exact quantitative predictions of system variables, on the one hand, and the importance of identifying trends and patterns produced by systems, on the other.

As suggested in the brief review above, the continuous increase in demand driven by population growth and economic development is a common thread in scenarios for water supply systems. Under this assumption, Kotir et al. (2016) discuss a system dynamics model assembled to study the possible evolution of the Volta River Basin in Ghana. Their model suggested that the best policy was investing in the development of water infrastructure in the region, in particular through the building of large and small-scale reservoirs and developing an appropriate infrastructure for agricultural use. Importantly, in a scenario closer to the one explored in this study – that is, the prevalence of drier conditions, denoted by a decrease of 30 per cent in precipitation and implying a reduction of 50 per cent in water availability – the limits to growth in the production of agricultural crops would be rapidly reached (by the year 2020). In other words, according to their model, water scarcity may affect food security, imposing in the end strong limits to population and economic growth, and decreasing societal well-being.

3. Method and results

The simulation model was developed following the sound tradition of the system dynamics methodology. The method was developed in the middle of past century by Jay Forrester (1961) to study complex business problems and was later expanded to study problems associated with the dynamics of growth and decline in urban centers (Forrester, 1969), in the world as a whole (Forrester, 1971b), as well as modern problems such as climate change. The approach consists in an iterative process to define a dynamic hypothesis, develop a formal model, test and validate it, and formulate and evaluate different intervention policies (Coyle, 1996; Richardson and Pugh, 1981; Sterman, 2000). Complex social problems that induce narrow short-term policies, such as the management of scarce resources and commons, benefit from the system dynamics modeling approach, which allows the integration of several theoretical frameworks to explain puzzling social phenomena. A detailed description of the system dynamics approach can be found in Sterman (2000) and Ford (2010).

The five steps proposed by Sterman (2000) were followed to develop a system dynamics model, which comprehends: the problem articulation, development of a dynamic hypothesis, formulation, testing and policy formulation and evaluation. An advantage of system dynamics models over simple mental models that command everyday actions of managers is the explicitness of its assumptions and of their relationships (Forrester, 1971a).

3.1 Dynamical hypothesis

The research problem addressed in this study is the evaluation of the resilience in the water supply system of the metropolitan region of São Paulo (MRSP). To accomplish this goal, a simulation model was developed, and three distinct hypothetical scenarios were designed to
evaluate the impact of potential threats to the system. Figure 4 presents a visual representation of the system.

The “MRSP Basin” is composed of several surface or underground water sources. The water is withdrawn from rivers, lakes, streams, dams and groundwater sources and then stored in artificial reservoirs before being canalized to several water treatment plants. After being treated, water goes to the distribution system from where it reaches final consumers. Following regular consumption, most water goes to sewage treatment plants, from where it reaches upstream water basins or downstream destinations, precluding, in the latter case, further use in the MRSP system.

The block diagram (Figure 4) also includes two relevant actors: “Water Authority” and “Consumers”. The Water Authority oversees several decisions in the system, for example, issuing grants to industrial and agricultural sectors, defining limits for the flows to water treatment plants; deciding on the maximum level of losses in the system; allowing the use of alternative water sources (e.g. underground water); and designing policies that affect the behavior of consumers. On the other hand, the attitude and behaviors of consumers affect the demand for the resource, as well as the search for alternative sources of water.

In the present study, only part of the elements represented in the block diagram was included in the final model. We decided to put the focus of the analysis on what we call the first layer of the system’s resilience, which depends on the water extraction limits imposed by current grants and on the existing supply capacity, including the losses in the system. In other words, we are analyzing how resilient is the system considering its current structure and regulatory context.

We are not analyzing how resilient the system could be, especially if more enlightened policies and regulations were in place – configuring a second layer of resilience, which, in practice, stays dormant in the case of the MRSP. Hence, optimization of the sewage subsystem, development of distant sources of water and investments in long-term sustainability of the water basins already incorporated into the system were excluded.

![Block diagram of the MRSP water supply system](image-url)
Nonetheless, we note a trend in the literature towards reconciling the traditional paradigm within water management systems, based on building dams, and the acknowledgment of ecological functions that ultimately support the existence of water sources (Poff et al., 2016). Hence, long-term sustainability of water basins tends to be incorporated in the repertoire of policies (or goals) that increase the resilience of water supply systems.

The scope of the final model encompasses the major dynamics explaining the water crisis experienced in the MRSP system. Table I shows the model boundary chart with three types of variables: endogenous; exogenous and excluded, as suggested by Sterman (2000).

The causal loop diagram (Figure 5) portrays the key variables and their causal links. It shows, in essence, the feedback structure of the system. Feedback loops can be positive or negative, as indicated by the corresponding symbol at the end of the arrow. Each closed loop represents a balancing ("B") or reinforcing ("R") behavior, depending on the set of polarities of the underlying relationships. Reinforcing feedback loops act to magnify the impact of changes from outside the loop while balancing loops act to negate the impact of the change from the outside (Ford, 2010). The CLD includes the main stock and flow structure for available water, decision processes and delays.

In the model, water available increases with water inflow and decreases with outflow to water treatment plants and losses and other uses. In turn, water inflow is a function of the rainfall and the basin conditions.

Figure 5 shows the three feedback structures that act to equilibrate the supply and demand for treated water. Loop “B1” shows the short-term effects of policies to curb demand. The fall in water coverage ratio triggers the enactment of those policies, after some delay. For simplicity, and as it is still not possible to clearly understand the effects of each independent action, all policies are represented in a single loop. As the policies produce their expected results, demand for water drops, reducing the outflow to water treatment plants.

Loop “B2” shows the long-term effects of policies aimed at decreasing population’s natural demand for water. It is also possible to consider that restrictions lead to different adaptive behaviors among consumers (such as looking for other sources of water), but as sufficient time has not elapsed to allow the identification of those effects in the MRSP system, they are omitted from the proposed model.

Finally, loop “B3” shows the supply reduction induced by low water levels. When available water decreases significantly, the Water Authority reduces the maximum outflow to consumers, following the regulation enacted by the National Water Agency (ANA/DAEE, 2017). Depending on the level of water available in the reservoirs, there is a different rate for maximum extraction (Table II).

<table>
<thead>
<tr>
<th>Endogenous</th>
<th>Exogenous</th>
<th>Excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actions of water authority</td>
<td>Water inflow</td>
<td>Actions to reduce losses</td>
</tr>
<tr>
<td>Basin conditions</td>
<td></td>
<td>Economic growth</td>
</tr>
<tr>
<td>Desired water supply coverage</td>
<td></td>
<td>Population costs</td>
</tr>
<tr>
<td>Distribution losses</td>
<td></td>
<td>Water Authority costs</td>
</tr>
<tr>
<td>Effects of Water Authority actions</td>
<td></td>
<td>Water operator profits</td>
</tr>
<tr>
<td>Population</td>
<td></td>
<td>Water sewage</td>
</tr>
<tr>
<td>Population water demand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water coverage ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water supply reduction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table I. Model boundary chart
3.2 Model formulation

Figure 6 shows the stock and flow diagram that contains the three previously described feedback loops.

The water that flows into the stock of “Water Available” depends on the “Basin Conditions” and the average water inflow (“Water extraction”). The average monthly inflows and their corresponding standard deviation were computed from data provided by SABESP, ranging from 2003 to 2017, excluding the period between 2013 and 2015, when the region suffered its most critical drought (SABESP, 2017b).

The “Water Available” stock has two outflows. One of them comprises the “Losses and other uses,” such as unauthorized uses and the random discard of water in the rare situations when reservoirs reach their maximum operational capacity (1855.8 \times 10^6 \text{ m}^3), and

<table>
<thead>
<tr>
<th>Bands</th>
<th>Volume</th>
<th>Allowed extraction rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1: Normal</td>
<td>\geq 60%</td>
<td>100</td>
</tr>
<tr>
<td>Band 2: Attention</td>
<td>\geq 40% and &lt; 60%</td>
<td>94</td>
</tr>
<tr>
<td>Band 3: Alert</td>
<td>\geq 30% and &lt; 40%</td>
<td>82</td>
</tr>
<tr>
<td>Band 4: Restriction</td>
<td>\geq 20% and &lt; 30%</td>
<td>70</td>
</tr>
<tr>
<td>Band 5: Especial</td>
<td>&lt; 20%</td>
<td>47</td>
</tr>
</tbody>
</table>

Source: Adapted from ANA/DAEE (2017)
Figure 6. Stock and flow diagram of the proposed simulation model.

- Desired Water Supply Coverage
- Water Supply Coverage
- Water Available (initial)
- Water Inflow
- Water Treatment Plants
- Outflow to Water Treatment Plants
- Water Availability Ratio
- Maximum Water Supply
- Maximum Outflow
- Minimum Time
- Average Inflow
- Water extraction
- Basin Conditions
- Drought Period
- Losses and other uses
- Table for Maximum Water Flow
- Table for Maximum Water Plants Capacity
- SWITCH for TIMWF
- SWITCH for EWCRWDST
- Effect of WCR on Water Demand Short-Term
- Effect of WCR on Consumption per Person
- Time to Adjust Population Demand
- Population Adjusted Demand
- Population
- Population Growth Rate
- Population Carrying Capacity
- Distribution Losses Fractional Rate
- Natural Growth Rate %
- Distribution Losses Fractional Rate
- Population Demand
- Consumption Variation
- Consumption per Person
- Long-Term Effect of Water Policy Reduction
- B1
- B2
- SWITCH for EWCRCP
- Time to Adjust Consumption per Person
- Goal for Consumption per Person
- Consumption GAP
- Goal for EWCRCP
- Table for EWCRCP
- Desired Water Supply Coverage
- Water Coverage Ratio (EWCRP)
- Water Coverage Ratio (EWCRDP)
the other represents the destination of the water resource to the treatment plants ("Outflow to Water Treatment Plants").

The variable “Total Water Demand” determines the rate of water that flows from the reservoirs into the water treatment plants. It depends on the total “Population” living in the MRSP, the estimated average monthly water “Consumption per Person” (190.82 ± 6.36 L/inhabitant/day) and the “Distribution Losses Fractional Rate” of water in the whole distribution system (29.38 ± 2.67 per cent relative to the water volume produced). The values for the parameters were obtained from SABESP (2016, 2017b).

When simulated, the model responds to a crisis in an expected manner. As the recent episode exemplified, under intense pressure to balance supply and demand, the system’s operators resort to all sorts of policies: financial incentives to reduce consumption, restrictions in water supply during some periods of the day (a policy criticized for lack of transparency and offhanded operations), awareness campaigns, etc. Evidence collected from SABESP, and other operators around the world, suggests that most behavior changes persist in the short-term, even after the memory of the crisis fades out and the restrictive policies are relaxed. People tend to incorporate many sustainable behaviors in their daily activities (e.g. not brushing teeth while keeping the faucet running), but over time, there is a tendency to abandon more stringent restrictions. The model also assumes that system’s operators, sensing the increased probability of new crises, start to develop over time new policies to influence the natural rate of consumption of water by the population. Typically, such policies require a longer time horizon to work. They include educational policies, incentives to adopt water-saving appliances, better regulation, etc.

3.3 Sensitivity analysis
Figure 7 shows the result of a sensitivity analysis considering a water system in equilibrium, with its inflow and outflow rates being equal to 10 per cent of the total volume of the reservoirs (maximum amount of storable water). In the initial condition of the system, it is assumed that the desired coverage time is six months and that the reservoirs are at 60 per cent of their full capacity.

![Figure 7. Results from the sensitivity analysis performed with the proposed model](image)
This initial equilibrium condition changes when the inflow rates start operating under different assumptions. In this case, inflow ceases to be constant and starts following a normal probability distribution with mean 10, standard deviation 1.7, maximum value of 15 and minimum value of 5 (the numbers are scaled to the magnitudes used in the rest of the simulation model). This "new" condition resembles an environment with more extreme variation in rainfall, which may be sufficient to stress a system designed under benign assumptions. Figure 7 shows the behavior of the "water coverage ratio" variable, which represents the ratio between the available water in the reservoirs and the desired water for consumption (according to the demand expectations from stakeholders in the system).

In this analysis, we assume that Water Authority does not undertake any short-term action to mitigate the problem and the only restriction is the constraint in supply caused by the extremely low levels of the reservoirs (in other words, a sheer physical limitation).

This simple exercise exposes an important weakness in the system, which shows a 5 per cent probability of total collapse in the period between 15 and 18 months, and a 25 per cent probability of collapse in the period between 15 and 29 months. Thus, the dynamics produced by the model is very similar to what was observed in the MRSP water system between 2014 and 2015, when it nearly collapsed. The behavior also resembles the fragility observed in other water supply systems throughout the world (e.g. Cape Town).

4. Base run and scenarios evaluation
In the next subsections, the resilience of the MRSP water system is analyzed under different scenarios, each representing a set of policies that could be adopted to address future periods of crises. In all scenarios, we consider short term a period of few months, and long-term a period of at least five years. The scenarios assume the system is stressed by an unusual pattern of water inflow (i.e. rain) as illustrated in Figure 1 – there is a sudden crisis in the system, whose resilience then depends on the policies undertaken by its body of management.

4.1 Individual interventions
This section presents the effects of each of the three balancing feedback loops described previously and the respective dynamic behavior of the system. Table III explains the scenarios. We broadly refer the demand from the different stakeholders (families and businesses) as population's water demand since residential consumption represents about 80 per cent of total consumption in the MRSP and the policies adopted to tackle the crisis targeted mostly the consumption of water by families.

The output representing the simulated dynamical behavior for each of the scenarios described in Table II is presented in Figure 8. The figure shows the behavior over time of the variables "water coverage ratio" and "population supply/demand ratio". The simulations confirm that the model can reproduce the response of the system to an episode of crisis similar to the one observed in the MRSP.

4.2 Combined interventions
Figure 9 presents the result of the combination of policies "B1" (short-term action) and "B3" (supply restriction) and the comparison with the adoption of each policy separately. Interestingly, during the crisis, policy "B3" dominates policy "B1". Only after some delay, their combination leads to slightly better results. Hence, it is possible to discern the lack of significant synergy between the two policies, although their combination may be more palatable in political terms, as it engages the population in the effort to address the crisis.
As said above, the balancing feedback loop “B2” (long-term policies) produces results only over a longer time span. Thus, we extend the time horizon for the simulation to 120 months. In this condition, there is no change in the behavior of the variable “population supply/demand ratio”, but there is a slight improvement in the behavior of the variable “water supply coverage”.

### Table III.
Simulated scenarios descriptions

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>Inertia prevails. There is no action taken by the Water Authority. When the water level drops to almost to zero, the population experiences a severe water supply restriction of approximately 40% of the desired demand within a short period of approximately three months.</td>
</tr>
<tr>
<td>Short-term actions (B1)</td>
<td>In this case, water availability also falls dramatically, reaching in short time values comparable to the “Base” scenario. During the peak of the crisis, water supply is restricted to about 70% of the population’s water demand for approximately eight months. The scenario closely resembles what happened in the metropolitan region of São Paulo during the drought of 2014-2015.</td>
</tr>
<tr>
<td>Long-term actions (B2)</td>
<td>The behavior is still similar to the “Base” scenario. Only by month 47, a slight difference emerges. Two inferences are drawn in this case: I) long-term actions seem to be ineffective during crises, and II) those policies must be maintained permanently to change consumers’ behavior.</td>
</tr>
<tr>
<td>Supply restrictions (B3)</td>
<td>Among the three policies, this one appears to have the most promising outcome in terms of for keeping adequate water levels and preserving the system’s supply coverage. However, it subjects consumers to massive restrictions on consumption. It is thus a widely unpopular policy, exposing underlying tensions among different stakeholders in the system.</td>
</tr>
</tbody>
</table>

Water used to be infinite

![Figure 8](image1)

Dynamic behaviors for each of the four scenarios described in Table III on the (a) water coverage ratio and (b) population water supply/demand ratio

![Figure 9](image2)

Individual and combined effects of the policies “B1” and “B3” on the dynamical behavior of (a) water coverage ratio and (b) population water supply/demand ratio
coverage ratio’ (approximately 5 per cent), as shown in Figure 10. In any case, the model suggests this policy does not help in managing short-term crises, and this is probably a reason why it tends to be overlooked in the normal repertoire of policies to improve the system.

5. Discussion and conclusion
The model presented in this study captures the main dynamics observed in the recent water crisis in the MRSP. As the system endured an unforeseen shock in the rates of water inflow, its operators resorted to a mix of supply and demand policies, in an attempt to cope with alarmingly low levels of available water. Fortunately, the following summers were sufficiently wet to recompose the system’s levels. Nonetheless, the episode revealed an underlying vulnerability that seems to persist in the system, as the simulations reported above suggest.

The model accounts for short and long-term effects. Immediately after a crisis, the system’s operators tend to resort to short-term measures such as penalties and positive financial incentives. However, over a longer time span and under continuous stress in the system (but probably not after a single episode of crisis), the natural course of action is the development of policies to reduce the normal (“natural”) demand for water and to increase its supply. Such policies may include incentives for storage of rainwater, smart meters, variable pricing, etc. In the model, such long-term effects may have been underestimated since the simulations considered only a single episode of crisis. In the context of real systems, a succession of droughts may lead to the adoption of radical, long-term policies, as the examples reviewed in Section 2.1 illustrate.

Regarding limitations, the model does not incorporate the role performed by the price of water (i.e. tariffs) in changing some dynamics in the system. For instance, better design of tariffs may punish the traditional lenience towards prevailing rates of water loss (“leakage”) in the system while also incentivizing policies to preserve the environmental quality of water basins. In other words, the model does not capture how better regulation could contribute to the system’s resilience. Also, the model does not represent the impact of better sewage treatment in increasing water availability. It also does not address issues related to reservoir management, such as sedimentation and streambank erosion, which may interact with the effects of climate change (e.g. by increasing the flushing of shallow soils), creating another layer of pressure into water
supply systems (Yasarer and Sturm, 2016). All these limitations remain as suggestions for future expansion of the model. Nevertheless, the dynamics discussed in this study seem to explain the system’s resilience (or the lack of it) in the short and medium terms, in particular considering that alternative policies typically require longer time horizons to produce their effects. We also leave for future expansions the possibility of developing an interactive simulation model with the goal of involving the different stakeholders in the process of searching for sustainable policies.

The time horizon for the occurrence of droughts is, of course, shorter in comparison to large-scale climate change. Nonetheless, there are several assertions in the literature linking the recent droughts throughout the world to anthropogenic climate change. If we move to an era of climate extremes, then current paradigms of water management supply may prove to be inadequate, as the Cape Town case illustrates. The game and its rules seem to be changing for good. The model developed in this paper suggests that the MRSP water supply system is ill prepared to deal with unexpected droughts and equally deficient to play this new game and its challenging new rules. Climate change will add increased complexity in the system. To stay in the analogy, nature will require chess players instead of experts in checkers. One has only to ponder the possibility of unexpected interactions between climate change and the broad natural and physical ecosystems in the upstream component of water supply systems.

This paper began by suggesting that water scarcity may be one of the earliest concrete signals of climate change. Perhaps societies need this kind of alert to start addressing such complex problems. In any case, the example of the MRSP water system suggests that shared mental models tend to reflect a time when abundance was taken for granted. Mental models are typically harder to change than physical systems. Hence, it is expected that greater resilience in the MRSP system will require paradoxically more exogenous turbulence from unexpected climate conditions, leading to policies that are more effective within longer time horizons. As the report on the management of extreme risks produced by the Intergovernmental Panel on Climate Change makes clear, transformative change often depends on enabling change in mindsets (IPCC – Intergovernmental Panel on Climate Change, 2012). Will the change require a collapse in water reservoirs? This remains an open question.

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A systemic methodology for the reduction of water consumption in rural areas

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Abstract

Purpose – This study aims to present a systemic methodological proposal for the reduction of water consumption in rural areas, based on participatory tools.

Design/methodology/approach – A theoretical framework was constructed based on the importance of stakeholders’ participation in the adequate use of the hydro resources, technologies to save water and modeling the adoption of possible water-saving technologies. After that, it was proposed a methodology for the reduction of water consumption in rural areas. This methodology was tested in a participatory study case, including the system dynamics model.

Findings – This study proposes a participatory systemic methodology – PAWAME – participation-water waste-technology-adoption-model-empowerment, which consists of four steps: identify stakeholders and the activities related with the waste of water in the study site and establish their values, measure the adoption that the technology would have based on the awareness generated, relate in a model the variables of the water-consuming activities and the variables of the technology and its adoption to analyze possible future behaviors and empowerment of the technology to reduce water consumption.

Practical implications – In Colombia, part of the population has the wrong perception about the abundance of the hydro resource, and for this reason, people do not use water in a correct way. The inclusion of a participatory systemic methodology was fundamental to apprehend the dynamic aspects of users’ behaviors, as well as of the management of the water resource. The model addresses the complexity of the situation, allowing exploring future scenarios of environmental protection.

Originality/value – This study advances the knowledge in participatory systemic methodology to design and adopt a local technology to save water.

Keywords Stakeholders, Participation, Water consumption

Paper type Research paper
Introduction

Water is a limited and irreplaceable resource, key for human well-being, essential to sustain life (Singh et al., 2010). One of the biggest problems that affects societies is the potable water supplying (catchment, treatment and delivering), especially in some regions of Colombia. A study from the Department of Protection of Citizens' Rights of Colombia shows that 5.4 from 13.6 million who live in rural areas do not have access to water supply systems, 8.2 million do not have sanitary units or sewage and just 1.5 million have access to potable water. In Colombia, lack of these services generates health problems such as being a representative cause of infant mortality and morbidity. Between 2004 and 2006, 20,000 children died because of diseases caused by poor water quality.

On the other hand, part of the population has the wrong perception about the abundance of the hydro resource, in particular, those in rural areas which have proximity to the paramos, because those provide around 70 per cent of the water of the big cities (Instituto Alexander van Humboldt, 2011).

To tackle the above problem, a group of professors and students from different universities co-designed together with the community a methodology that contemplates the generation of awareness and creation of a technology to contribute to the reduction of water consumption in the rural area and contribute with the quality of life of different communities.

The purpose of this article is to present the methodology that was co-designed and to show the results of its implementation in a study case. Accordingly, the structure of this paper is as follows:

- A theoretical framework is presented in which is highlighted the importance of the participation of stakeholders, the mechanisms and technologies that contribute to saving water and the way in which adopting a certain technology can be modeled.
- An analysis of the theoretical implications of this framework.
- Systemic methodology propose.
- The case study of the Reserva Encenillo is analyzed.
- Finally, the main conclusions about this application are presented, along with suggestions for future works.

Theoretical framework

In this section, a literature review is presented in which is highlighted the importance of the participation of stakeholders to achieve solutions for the water waste reduction. Also, are presented mechanisms and technologies that contribute to saving water and the way in which adopting a certain technology can be modeled to analyze the results of its implementation.

Stakeholder participation in water-consumption experiences

To develop a proposal where adequate use of the hydro resource is generated, it is necessary to develop an interest in designing and maintaining an optimal management process. In consequence, a bibliographical review is carried out to understand how different stakeholders can generate a contribution in this kind of processes. As Tweneboah (2016) uphold, deciding which direction to go requires stakeholder participation and consensus.

Linkov et al. (2009) present a model where the heart of the hydro management is brainstorming and the development of workshops so that those making decisions make them in the moment of the design itself. Bates and De Roo (2000) argue about the need for a
permanent articulation between those called decision-makers, meanwhile Morss et al. (2005) emphasize in the articulation between those who model and those who make decisions. Based on the above, methodological proposals that include participation of different stakeholders have been built to generate interactive models.

In that sense, the authors of previous articles emphasize in the relevance, not only of the technical solution, but also of the interactivity from the stakeholders in the design of the whole model. This model was called the interactive water simulation model, designed by researchers of Delft University of Technology. This model includes:

1. **Understanding** the needs of the stakeholders who manage water, and therefore understand the technical requirements of a proposal using semi-structured interviews; and

2. **Reaching** technical modeling based on the needs and variables that include simulations, testing and visualization of results.

Fratini et al. (2012) add a fundamental financial analysis that includes the description of current practices in urban water management and the identification of barriers and opportunities for sustainable transactions. This framework implies:

1. In the first phase, a macroeconomic research based on existing literature should be made (benchmarking)
2. Stakeholder analysis is carried out based on a recollection of qualitative data. The objective is to collect micro-knowledge to give a first description of the situation that the companies are studying. Finally
3. The identification of patterns that should be considered and used within the meso dimension.

What is relevant of these proposals is that the selected variables for simulation must have an impact over the economic, social and environmental setting of all interested parties, and that the latter strengthens any hydro resource optimization model that may be proposed (Jiménez and Pérez-Foguet, 2011).

**Technologies and mechanisms identified to achieve water savings**

There are different technologies that could be implemented by communities to contribute with water savings. One kind of technology is the one that allows obtaining water from sources other than rivers or lakes such as rainwater gathering or fog collection systems. These technologies are of major help for the communities that lack access to water from an aqueduct or do not have rivers or brooks nearby from which they can obtain water to satisfy their needs. It should be considered that not all zones have a high precipitation or fog index, so this type of technologies do not apply for all contexts (Pascual and Naranjo, 2011).

Other technology is the cold-water diverting systems which allows to redirect water from the shower until it starts to warm up (Castelazo, 2014). The faucet aerators are devices that can be screwed in the mouths of the faucets to incorporate air to the jet of water, and thus reduce the consumption of water without diminishing the quality, saving more than 40 percent of water (Agenda 21 Local de Salamanca, 2010). Water meters are devices that count the water that passes through them, helping thus to raise awareness, and in some cases, decrease the regular consumption of water. In a dry toilet, feces are separated from urine, urine can be treated along with graywater or stored for later use in irrigation, and feces can be treated by dehydration, composting or anaerobic fermentation and serve as a fertilizer (Conant and Fadem, 2012).
This system of dry toilets has been implemented in several parts of the world such as Ecovillage El Romero in La Serena, Chile (Ecoaldea EL ROMERO, 2014). Another case in Chile is the Ecocenter Eluwn, which is being developed since 2004 in Loica (Commune of San Pedro, Province of Melipilla), just 110 km from Santiago de Chile (Ecocentro Eluwn, 2018). In Colombia, there are places where this system has been implemented; such is the case of Palomino, Guajira.

There are other technologies which do not require the use of infrastructure but are related with changes in the behavior of the user, adjustments in value, social and individual aspirations, financial incentives, ethical and moral imperatives and changes in government and laws/regulations (Roccaro et al., 2011).

Modeling of the adoption of a technology
Having reviewed the experiences of stakeholders’ participation in water management, and once a review of the technologies that allow water saving in rural and semi-rural areas has been made, this section intends to introduce a way for modeling the adoption of a technology to achieve such savings. Modeling is important because, as Zhang et al. (2010) says, the water resources system is characterized by non-linearity and multi-way of feedback.

Forrester, creator of the system dynamics, highlights the importance of describing the way in which a system variable influences the others through time. A model of dynamics can provide information at lower cost and enable the achievement of a faster knowledge of the conditions that are not observed in real life. In this case, system dynamics is a tool that leads to identify all the variables that affect other variables and to what extent they do it (Forrester, 1987). As Salhieh and Singh (2003) said, an advantage in adopting system dynamics as an analytical tool is that it displays the many interrelationships that influence the behavior of a complex system. A system is defined as “a set of parts in interaction which satisfy a certain objective” (Tarride, 2006). Besides, system dynamics modeling helps in bridging organizational hindrances to their change, if the change is required (Ambroz and Derencin, 2010).

The relations between the water infrastructure system, its environment and the social system become of foremost importance because, whenever a certain technology is being considered for being used, it should be considered the role that people play in the process, because they are the ones that generate awareness and make action adopting decisions based on it. Hamid et al. (2017) support that changes in behavior are brought through raising awareness regarding an issue and by fostering an appropriate attitude. Etzion (2014) proposes that it is not only necessary to decide whether awareness was generated or not, but also if once awareness is generated, action was adopted. In this manner, the adoption decision also depends on the benefits that the person sees in the action when he/she evaluates if these are greater than the costs. Additionally, it is important to highlight that the awareness and adoption decision can change, and one of the factors that influence this is the adoption decision that others take. To the extent that the number of people adopting the action increases, it will generate greater adoption by other people.

A particular model, used by Sterman, is the Bass model, proposed by Frank Bass, which is one of the most relevant models to describe and forecast the diffusion of innovation. The Bass model is about the adoption and dissemination of new products and technologies. This model allows to estimate the number of consumers who will adopt (begin to use) a new product or technology over time. There are two types of adopters, some are considered innovators who dare to adopt a technology independently from what the rest of the society does and others are the so-called imitators who begin adopting a technology once they observe that there are others already using it (Sterman, 2000). Based on the aforementioned, it can be sustained that both types of adopters are two types of stakeholder with different
interests, which makes this Bass model fit to model pluralist systems and in particular, systems where analyzing the adoption of a technology is wanted. Figure 1 shows the diagram of the Bass model.

The Bass model is defined as follows (Sterman, 2000):

\[ AR = aP + c_iPA / N \]

Where:
- \( AR \) = number of consumers who adopt the product in the moment \( t \);
- \( A \) = persons who have adopted the technology;
- \( N \) = total population;
- \( i \) = imitation coefficient. This is the probability that an imitator adopts the new product by having contact with an adopter. This coefficient reflects the effect that already existing consumers can produce over potential consumers;
- \( c \) = contact rate between potential adopters and adopters;
- \( a \) = coefficient of innovation. This is the probability that an innovator buys or adopts the product in a \( t \) period; and
- \( P \) = potential persons to adopt.

Based on the above, it can be said that a high value in “\( a \)” indicates that the new product will be adopted rapidly even though it has a low probability of imitation, whereas a low level of “\( a \)” will make adoption slower even though “\( i \)” has a high value, because imitators have a small group of innovators to copy. The number of imitators grows first at an increasing rate and later at a decreasing rate until it reaches a peak of adopters (Weissmann, 2008).

**Theoretical framework analysis**

From the analysis of the previous theoretical framework, two extensive ideas can be concluded:

*The intervention methodology should be based on agents of change in the communities*

The intervention of different stakeholders is necessary for the proper water use in different contexts. In the theoretical framework, there is evidence about the relevance of

![Bass model of diffusion](image)

*Source:* Sterman (2000)
the intervention of different interested parties in the management of such a valuable resource as it is the hydro one. The question that will remain is, if the situation was not felt as an immediate and of their own problem, would it be included in the main problems to be solved? In the best of cases, it would. However, that would not necessarily guarantee learning and feasible process permanence in the long term. In that sense, why do not think about designing a participatory methodology where learning can be the fundamental scenario for water protection? To include the new generations of the communities as active managers of the maintenance of natural resources supported in the learning process inside the schools, Colombia has to follow South Africa’s steps, where water conservation is already being integrated into the teaching curriculum, and further publicized and implemented within surrounding communities (Oliver and Brümmer, 2007).

Technologies should be combined with social competences in the communities.
It is not enough to identify the shortage of water. It is necessary that the different agents in the community understand in a systemic manner the problem associated with such shortage. In that sense, it is necessary to identify the direct and indirect variables to make long-term decisions to generate innovative savings and optimization solutions. Furthermore, the adoption of the innovative technology is relevant if the different agents in the community understand that the decisions made will have an impact over many variables. Therefore, such adoption of technologies must be based in systems where each agent understands how their own decision makes a sense over the optimization of the system as a whole. To facilitate this, it is possible to relate all the variables involved in a diagram or a model to see how changing of a variable affects other variables.

Methodological proposal for the reduction of water consumption
Based on the problem of water shortage presented in the introduction and the conclusions obtained from the analysis of the theoretical framework, in this section is proposed the methodology – PAWAME – participation-water waste- adoption-model-empowerment. PAWAME is a methodology that contributes to the reduction of water consumption in rural areas through the introduction of a technology and awareness generation. PAWAME can be considered as a participatory methodology because it considers the opinion of the different stakeholders of the system. Besides, PAWAME is a systemic tool because as Bunge (as cited in Johannessen, 2012) says, concerns the study of social systems and the relationships within and between them and how it relates to the outside world. In Figure 2, the graphic of the proposal is presented, and in Table I, each step of this proposal is explained.

The following is a detailed description of each of the steps of the PAWAME methodology.

Participation
Based on the need of build solutions for the water waste in a collective way, it is necessary to involve in the proposed methodology permanent activities of participation. It is important that the community participates during the evaluation of their problem and in the implementation of projects focused on natural resources and their sustainability. This method is appropriated to work with rural communities because it helps the emergency of sustainable solutions, generates a progressive change in the society, increases the community participation degree and allows feedback and adjusts to the proposes. Besides, systemic participation allows organizations to contribute to the community as part as their social responsibility programs, opening to real problems and
search real solutions and generate educational and investigative process that involves all the stakeholders (Ramírez et al., 2011). Consequently, each letter of the methodology is joined by “P” of participation.

**PW – identify stakeholders and the activities related with the waste of water in the study site and establish their values**

In this stage, the aim is to identify the main stakeholders, and together with them, list all the activities in which water is consumed in the study site (toilet, shower, bathroom sink, dishwasher sink, agriculture, livestock, etc.). After obtaining a list of activities, the variables that influence each activity are identified, and values to each of these variables are assigned. At this point, all the different water flows, such as the dishwasher, sink and shower, are gauged, if applicable. It is recommended to use the methodology described below in methodology to calculate amount of water spent to calculate the amount of water spent on the different activities.

To gauge sink, dishwasher and shower, perform the following steps:

- Grab a measuring cup and a stopwatch.
- Open the faucet and count the time it takes to fill the container.
- Calculate the container volume.
- Count the time it takes a sample of persons to wash their hands.
- Calculate the average time a person takes in washing their hands.
- Calculate the amount of water being spent with the following formula:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PW</td>
<td>Identify stakeholders and the activities related with the waste of water in the study site and establish their values</td>
</tr>
<tr>
<td>PA</td>
<td>Measure the adoption that the technology would have based on the awareness generated</td>
</tr>
<tr>
<td>PM</td>
<td>Relate in a model the variables of the water-consuming activities, the variables of the technology and its adoption to analyze possible future behaviors</td>
</tr>
<tr>
<td>PE</td>
<td>Empowerment with the technology to reduce water consumption</td>
</tr>
</tbody>
</table>

**Table I. PAWAME methodology outline**

**Figure 2. PAWAME methodology structure**
Water spent per person \(\text{[volume]}\) = \(\text{container volume} \times \frac{\text{average time a person washes hands}}{\text{time in which the container is filled}}\)

To determine the volume of water spent per flush in a toilet, perform the following steps:

- Measure the area of the base of the toilet tank.
- Measure the initial height of the water before flushing.
- Measure the height of the water after flushing.
- Calculate the volume of water spent per flush with the following formula:

\[
\text{Water spent per flush [volume]} = \text{tank area} \times (\text{water height before flushing} - \text{water height after flushing})
\]

To calculate water spent in agriculture and livestock, perform the following steps:

- Measure the dimension of the tank used for irrigating the crops or livestock.
- Count the number of tanks used to feed the crop or livestock.
- Calculate the volume of water spent in irrigating crops and livestock with the following formula:

\[
\text{Water spent in irrigation or livestock [volume]} = \text{volume of the tank} \times \text{number of tanks used in irrigation or livestock}
\]

PA – measure the adoption that the technology would have based on the awareness generated. Through workshops and focus groups with stakeholders, select the technologies that are appropriate for the community considering at least the following criteria:

- Replicability: technology must be able to be implemented in different places.
- Low cost: the elements that make up the technology should be low cost, as well as its maintenance.
- Easy to build: technology should allow the community to get involved in its construction.
- Easy installation: the technology must be able to be adapted to the housing conditions of the communities of the region and must be able to be installed by the same community.

It is recommended to make a table with the possible technologies and their criteria which will be used to select the most appropriate ones (Table II). A certain weight should be applied to each criterion based on the opinions of the stakeholders, and therefore it will be possible to determine which technology to implement. Doing this comparison is important to

<table>
<thead>
<tr>
<th>Technology</th>
<th>Replicate</th>
<th>Low cost</th>
<th>Easy to build</th>
<th>Easy installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology #1 (Example)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Technology #2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Technology #3</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Technology #4</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Technology #5</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Table II. Competition of technologies according to criteria
make sure that the technology that selected is appropriate in the context, considering the expertise of the community members and the resources that they have.

In this step, the adoption of the selected technology and awareness of savings are determined through surveys. These surveys can be formulated with two questions, one initial and one final, each one with two options of responses established, from which one option must be chosen. The reason for choosing this type of surveys is that they allow eliminating the ambiguity factor and their use requires less time. Tables III and IV show examples of answer options for different technologies, but the survey should be made considering only the technology selected in Step 2.

The initial question is: Which of the following options do you prefer? Mark with an “x”.

The final question: Think about the consequences that may carry the choice you have made in the initial question and answer. Which of the following options do you choose? Mark with an “X”.

As it is shown in Tables III and IV, for each question, there are two options for answer. For the case of the initial question, marking option A indicates that there is an initial

<table>
<thead>
<tr>
<th>Technology</th>
<th>Option A</th>
<th>Option B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry toilets</td>
<td>Use a dry toilet</td>
<td>Use a conventional toilet</td>
</tr>
<tr>
<td>Rainwater gathering system</td>
<td>Collect and use rainwater</td>
<td>Not collecting rainwater and using tap water</td>
</tr>
<tr>
<td>Cold-water diverting systems in showers</td>
<td>Install a cold-water diverting system in showers</td>
<td>Let cold water run in showers until it is hot</td>
</tr>
<tr>
<td>Faucet aerators</td>
<td>Install faucet aerators</td>
<td>Keep faucets without aerators</td>
</tr>
<tr>
<td>Water meters</td>
<td>Have water meters to keep track of consumption</td>
<td>Not having water meters to not worrying about consumption</td>
</tr>
<tr>
<td>Fog collection systems</td>
<td>Use water harvested in a fog catcher</td>
<td>Use tap water</td>
</tr>
</tbody>
</table>

**Table III.** Initial question to measure the adoption of the initial technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>Option A</th>
<th>Option B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry toilets</td>
<td>Use dry toilet + have enough water in 10 years to take a shower daily</td>
<td>Use conventional toilet + not having enough water in 10 years to take a shower daily</td>
</tr>
<tr>
<td>Rainwater gathering system</td>
<td>Collect and use rainwater + have enough water in 10 years to take a shower daily</td>
<td>Not collecting rainwater and using tap water + not having enough water in 10 years to take a shower daily</td>
</tr>
<tr>
<td>Cold-water diverting systems in showers</td>
<td>Install a cold-water redirection system in showers + have enough water in 10 years to take a shower daily</td>
<td>Let cold water run in showers until it is hot + not having enough water in 10 years to take a shower daily</td>
</tr>
<tr>
<td>Faucet aerators</td>
<td>Install faucet aerators + have enough water in 10 years to take a shower daily</td>
<td>Keep faucets without aerators + not having enough water in 10 years to take a shower daily</td>
</tr>
<tr>
<td>Water meters</td>
<td>Have water meters to keep track of consumption + have enough water in 10 years to take a shower daily</td>
<td>Not having water meters to not worrying about consumption + not having enough water in 10 years to take a shower daily</td>
</tr>
<tr>
<td>Fog collection systems</td>
<td>Use water harvested in a fog catcher + have enough water in 10 years to take a shower daily</td>
<td>Using tap water + not having enough water in 10 years to take a shower daily</td>
</tr>
</tbody>
</table>

**Table IV.** Final question to measure the adoption of the initial technology
adoption of the technology, while marking option B shows no initial adoption of the
technology. In the case of the final question, marking option A indicates awareness of
saving, while marking option B shows a low saving awareness.

After applying the questions, the number of people who marked option A is added for
each question and divided by the total number of surveyed people. The difference between
the value obtained for the final question and the initial question, multiplied by 100, is
considered the percentage of increase of awareness in the community after knowing the
possible consequences between whether adopting the technology or not.

**PM – relate in a model the variables of the water-consuming activities and the variables of
the technology and its adoption to analyze possible future behaviors**

Having identified the activities related with the water expenditure, the appropriate
technology for reduction in water consumption, and the adoption that this would have, the
model can begin to be developed using system dynamics. It is recommended to use
the model of Figure 3, based on the Bass model, to model the adoption of the technology.
This model was constructed in the software Vensim, which is a free modeling software. It is
important that stakeholders who have access to the internet download the software from
http://vensim.com/free-download/http://vensim.com/free-download/ and make the model,
following the instructions presented at http://vensim.com/building-a-simple-vensim-model/
Other software to create system dynamics models also can be used.

**PE – empowerment of the technology to reduce water consumption.**

After the values of the variables were introduced in the model, the amount of water that
could be saved if the technology is assessed. Then, there are some questions that the
community and the users should answer to begin the self-building process:

![Figure 3. Model for adoption of the technology](https://example.com/fig3.png)

**Notes:**
- **Attend workshops** = \( \text{Population} \times \text{percentage of people who dont want to use the technology} \)
- **People that go from not adopting to adopting** = \( \text{POTENTIAL ADOPTERS} \)
- **Percentage of people that adopt after workshops** = \( \frac{\text{ADOPTERS} + (\text{ADOPTERS} \times \text{Attend workshops}) \times \text{rate that adopts after someone else adopts} \times \text{POTENTIAL ADOPTERS} \times \text{Percentage of people that adopt after workshops} \times \text{Percentage of people that develop awareness through workshops}}{\text{Population}} \)
Is it significant and sufficient the amount of water saved?
Do we think that this kind of technologies help to reduce water consumption? Why?
What materials do we need to start building the technology?
Do we have some of the materials that we need to build the technology? Where are they? How can we get them if we do not have them?
When and how are we going to start technology building?

Once the technology has been built, it should be overseen and monitored. For this, some of the questions that should be answered to self-evaluate the process are as follows:

- What kind of lessons do you think that a process like that leaves to the community?
- Have we used the technology? Why?
- Do we consider that these kinds of technologies are easy to replicate?
- After the building experience, have we made concrete actions which permit the water reduction? Has the technology building process contributed in the design and implementation of these actions?

Application case
The methodological proposal was applied as a study case in Reserva el Encenillo located in the Guasca municipality, in the Guavio province in Cundinamarca. The Guavio province comprises the municipalities of Guasca, Gacheta, Ubalá, Gachalá, Junín, Guatavita, La Calera and Gama. It is a region that has on its surface hydro tributaries and paramos. This territory supplies 70 per cent of the water consumed in Bogotá and 20 per cent of the energy of the country (Cámara de Comercio de Bogotá, 2010). This fact leads part of the population to mistakenly assume that there is an abundance of the hydro resource, which is not the case due to factors such as the climate change and unregulated economic development that has a negative impact on the hydro resources of these regions and endangers its hydro sustainability (IDEAM, 2014).

Reserva el Encenillo is a biological reservoir that seeks to preserve the Encenillo woods, as well as their fauna and flora, particularly some bird and vegetal species, which are unique to the region. The reservoir is located in the Pueblo Viejo sector, in the vereda[1] La Trinidad of the Guasca municipality on the Cundinamarca department. It covers an area of 18,679 hectares, it has an altitude of 2,800 to 3,200 MAMSL, and temperatures ranging between 4°C and 21°C (Fundación Natura de Colombia, 2016).

The reservoir has a visitors center and an administrative headquarters with auditorium, bathroom facilities, dining area and a small eco store with souvenirs from Encenillo. It also has six walking paths, camping zone, carries out several activities such as bird watching, company’s events, environmental education and lectures on biodiversity and hydro resources conservation, among others. If an activity requires water, it is gathered from the nearby springs, and they do not pay a significant amount for its use (Fundación Natura de Colombia, 2016).

Reserva el Encenillo was interested in engaging in water-saving practices to be consistent with its mission and with the lectures offered about the proper use of the hydro resource. They did not have any kind of tools that allowed them to measure the quantity of water they were using, and they thought that this type of tool could generate a positive impact regarding the reduction of water consumption and the awareness of the visitors.

Specifically, the goal was to make Reserva Encenillo became a space for the students, teachers and community in general to be acquainted with the technology, create awareness...
about the importance of the correct use of water and start acting according to these using technologies which reduce water consumption. In the study case, it was working with 1,500 students from Cundinamarca who were part of Strengthening of the Community’s Management of the Hydro Resource Project of Gobernación de Cundinamarca (Cundinamarca Governorate).

Below, the development of the methodology is described in detail.

PW – identify stakeholders and the activities related with the waste of water in the study site and establish their values

As Hesamamiri and Bourouni (2016) mention, to model a system, an analyst should start by defining the problem or the issue at hand and identifying the scope, the boundaries of the study and the stakeholders (Table V). Initially, by means of interviewing an employee of the reservoir and the person in charge of it, the activities of the reservoir involving water consumption were identified; afterward, the variables that affect these activities were identified, and their values were calculated in a participatory way with the reservoir’s members. Table VI presents this information along with the measurement method.

PA – measure the adoption that the technology would have based on the awareness generated

Out of the technologies for reducing the consumption of water proposed in the theoretical framework, dry toilet technology was chosen in the study case because in this particular case, all the criteria had the same degree of importance for the stakeholders. This technology (like the rainwater gathering and the fog collection systems) fulfilled all the relevant criteria for the implementation of a technology in a rural area (Table VII). It is important to mention that, for completing the comparison table, was taken in to account the opinion of the stakeholders and the community.

The reason that the dry toilets system was chosen over the rain water gathering and the fog collection systems is that, among the three systems, this was the only one that leads to a reduction of water consumption because, as it was explained before, it does not use water for discharge. Hence, it generates a water consumption reduction of approximately 3,536 liters per month, assuming that all the visitors use this toilet and taking as reference the 2014 monthly average number of visitors, 325 people:

\[
\text{Water used per toilet per person} = \text{Water used per flush} * \text{Average number of times a person uses the toilet during the day} * \text{Average number of person in a month} = 5.44 \frac{l}{\text{flush}} * 2 \frac{\text{flushes}}{\text{person}} * 325 \frac{\text{people}}{\text{month}} = 3536 \frac{l}{\text{month}}
\]

---

**Table V.**

<table>
<thead>
<tr>
<th>Actors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gobernación de Cundinamarca</td>
</tr>
<tr>
<td>3 Administrator of Reserva Encenillo – Fundación Natura member</td>
</tr>
<tr>
<td>4 Employee of the reservoir</td>
</tr>
<tr>
<td>5 1,500 students of secondary education institutes from Cundinamarca</td>
</tr>
<tr>
<td>6 Teachers of secondary education institutes from Cundinamarca</td>
</tr>
<tr>
<td>7 Professors and students of Universidad de los Andes and Universidad Minuto de Dios</td>
</tr>
<tr>
<td>8 Funcener (foundation with experience in the field of renewable energies)</td>
</tr>
</tbody>
</table>

---
Based on the Technologies Assessment for Provision of Essential Services in Institutional Housing report Alcaldía Mayor de Bogotá (2010), the different scenarios proposed were evaluated to determine which one presented the best toilet proposal for implementation. The scenario number five was chosen because:

Table VI: Water expenditure activities in Reserva Encenillo

<table>
<thead>
<tr>
<th>Activity</th>
<th>Variable</th>
<th>Units</th>
<th>Value</th>
<th>Measurement method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crops irrigation</td>
<td>Water used per crop</td>
<td>Liters/crop</td>
<td>10</td>
<td>Interview with an employee from Reserva Encenillo</td>
</tr>
<tr>
<td></td>
<td>Number of crops</td>
<td>Crops</td>
<td>1</td>
<td>Interview with an employee from Reserva Encenillo</td>
</tr>
<tr>
<td>Cleaning</td>
<td>Water used in cleaning</td>
<td>Liters/cleaning</td>
<td>98</td>
<td>Volume measured after using the storage tank</td>
</tr>
<tr>
<td></td>
<td>Number of cleanings</td>
<td>Cleanings/month</td>
<td>8</td>
<td>Interview with an employee from Reserva Encenillo</td>
</tr>
<tr>
<td>Cattle feeding</td>
<td>Water consumed per animal</td>
<td>Liters/day/Animal</td>
<td>80</td>
<td>Interview with an employee from Reserva Encenillo</td>
</tr>
<tr>
<td></td>
<td>Number of animals</td>
<td>Animals</td>
<td>60</td>
<td>Interview with an employee from Reserva Encenillo</td>
</tr>
<tr>
<td>Toilet flushing</td>
<td>Water used per toilet flush</td>
<td>Liters/flush</td>
<td>5.44</td>
<td>Measurement of the volume of water used per flush through the methodology proposed in the design stage</td>
</tr>
<tr>
<td></td>
<td>Average number of flushes per person</td>
<td>Flashes/person</td>
<td>2</td>
<td>Observation during a visit to the Reserva Encenillo</td>
</tr>
<tr>
<td></td>
<td>Average number of visitors</td>
<td>Visitors/month</td>
<td>325</td>
<td>2014 data supplied by the Fundación Natura</td>
</tr>
<tr>
<td>Handwashing</td>
<td>Average time to wash hands per person</td>
<td>Minutes/person</td>
<td>0.16</td>
<td>Times measured in the Reserva Encenillo during a visit from university students</td>
</tr>
<tr>
<td></td>
<td>Water consumed per time using the sink</td>
<td>Liters/minute</td>
<td>1.98</td>
<td>Bathroom sink flow rate according to the methodology proposed in the design stage</td>
</tr>
<tr>
<td></td>
<td>Average number of visitors</td>
<td>Persons/month</td>
<td>325</td>
<td>2014 data supplied by the Fundación Natura</td>
</tr>
<tr>
<td>Shower</td>
<td>Average time in the shower per person</td>
<td>Minutes/person</td>
<td>10</td>
<td>Supposition based on observation</td>
</tr>
<tr>
<td></td>
<td>Water consumed per time in the shower</td>
<td>Liters/minute</td>
<td>2.16</td>
<td>Shower flow rate according to the methodology proposed in the design stage</td>
</tr>
<tr>
<td></td>
<td>Average number of visitors</td>
<td>Persons/month</td>
<td>325</td>
<td>2014 data supplied by the Fundación Natura</td>
</tr>
<tr>
<td></td>
<td>Average percentage of visitors that stay overnight</td>
<td>NA</td>
<td>0.05</td>
<td>Interview with an employee from Reserva Encenillo</td>
</tr>
<tr>
<td></td>
<td>Time that cold water comes out before the hot water comes out</td>
<td>Seconds</td>
<td>10</td>
<td>Times measured in the Reserva Encenillo</td>
</tr>
<tr>
<td>Dish washing</td>
<td>Time the water faucet is turned on for washing dishes in a day</td>
<td>Minutes</td>
<td>15</td>
<td>Interview with an employee from Reserva Encenillo</td>
</tr>
<tr>
<td></td>
<td>Water used for washing dishes per time the water faucet is turned on</td>
<td>Liters/minutes</td>
<td>3.36</td>
<td>Kitchen sink flow rate according to the methodology proposed in the design stage</td>
</tr>
</tbody>
</table>
(1) it does not use water for the evacuation of the excreta;
(2) a disposal in situ of the excreta is considered; and
(3) there are conditions suitable for the use of the soil for graywater treatment

Hence, it was decided that the most appropriate toilet technology to develop in the Reserva el Encenillo was a dry toilet similar to a VIP latrine (ventilated improved pit). This type of latrine uses a ventilation tube to prevent foul odors, and it is not expensive, and it is easy to build. However, the technology that was to be implemented was not the latrine but a dry toilet because, unlike the latrines, dry toilets allow for a separation of feces and urine, which prevents foul odors and permits to use afterward the urine as fertilizer and the feces as compost.

To assess the average adoption among the community, a sample of 150 students involved in the Strengthening of the Community’s Management of the Hydro Resource Project was taken into consideration; this sample corresponds to 10 per cent of the total of participants. In total, 90 students were asked to answer the two questions related to the dry toilet technology (Tables III and IV). The results obtained are shown in Figure 4.

Regarding the initial question, Figure 4 shows that, in the beginning, 21 per cent of the families surveyed preferred the dry toilet, and that this percentage increased to 79 per cent (an increase of 58 per cent) after they knew that this type of toilet may result in an improved water supply in the future, in comparison with the conventional toilet. Based on these particular awareness results, it can be argued that, through a training process that informs of the consequences of the wrong management the hydro resource, it achieved an increase in the water-saving awareness and the adoption of the technology which permits it.

PM – relate in a model the variables of the water-consuming activities and the variables of the technology and its adoption to analyze possible future behaviors

To relate the variables of the water-consuming activities to the variable of the adoption of the technology (Table VIII) and the variable of total water consumption, and to understand

Table VII. Technologies and criteria in the study case

<table>
<thead>
<tr>
<th>Technology</th>
<th>Replicate</th>
<th>Low cost</th>
<th>Easy to build</th>
<th>Easy installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry toilets</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Rain water gathering system</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Shower cold-water diverter system</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Faucet aerators</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Water meters or counters</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Fog collection systems</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Figure 4. Water-saving awareness regarding the use of dry toilet
the implications of decisions, a model in Vensim was developed with different stakeholders (Figure 5). Based on this model, some figures of the current water consumption in the Reserva el Encenillo were obtained. The yearly average water consumption is almost 50,000 liters in the Reserva Encenillo; whereas Figure 6 shows that the implementation of this technology would lead to a saving of approximately 35,000 liters per year.

**PE – empowerment of the technology to reduce water consumption**

To self-build the dry toilet in the Reserva Encenillo, the questions proposed in the design stage were answered. Initially, a design in Sketchup was proposed (Figure 7); it used cement and brick as the main material for the structure. Based on the advice of Funcener, a foundation dedicated to the research, development and production of knowledge and experience in the field of renewable energies applied to projects that impact positively the

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Value (%)</th>
<th>Measurement method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of people who adopt after workshops</td>
<td>Percentage</td>
<td>58</td>
<td>Survey conducted with 150 persons</td>
</tr>
<tr>
<td>Rate of people who adopt after someone else adopts</td>
<td>Percentage</td>
<td>0</td>
<td>Supposition</td>
</tr>
<tr>
<td>Percentage of people who do not want to use the technology (in a beginning)</td>
<td>Percentage</td>
<td>79</td>
<td>Percentage obtained based on the initial question (Table III). It corresponds to the percentage of people that prefer the conventional toilet</td>
</tr>
</tbody>
</table>

**Table VIII. Variables of adoption of the technology**

**Notes:** Total wasted water without dry toilets = Population * Water wasted per tank discharge * average tank discharges per person; Saving water = People who go from not adopting to adopting * Water wasted per tank discharge * Average tank discharges per person.
environment and human ecology projects (Funcener, 2015), and that has considerable background in dry toilets, it was decided to use the earthship technique for building the dry toilets. The earthship technique is based on taking advantage of the soil properties and in the utilization of recycled materials for construction. Therefore, not only is water being saved but also there is a good management of solid waste.
For the new design, it was proposed to replace the brick with wood and the cement with tires, soil and mud. In this way, the materials available in Reserva El Encenillo were taken into consideration, and tires, which are usually regarded as trash and piled up in the streets, were taken advantage. The self-build of the technology in Reserva el Encenillo began on 15 May 2015, with advisory from Funcener. It is described as a self-build process because the community by itself started the building of the dry toilet. That day, a workshop took place, organized by the Project for the Strengthening of the Community’s Management of the Hydro Resource, with the participation of members from the community and representatives from the institutions attached to the project. Among the latter, there were coordinators, teachers and students from educational institutions who up to that moment had stood out due to their performance in the project. The workshop began with a context presentation to inform the participants of the objectives of the workshop, followed by a theoretical explanation of what is a dry toilet, its utility and how to use it. After this first part, a practical workshop was carried out in which the building of the dry toilet took place, through workstations in which the stakeholders interacted and made use of the different materials to achieve it (Plate 1).

After the construction of the dry toilet, different members of the region have visited Reserva Encenillo and have had the opportunity to see the dry toilet. According to the reservoir’s administrator, this kind of technologies “Provide an opportunity to reflect on the cost of using water in bathrooms and offer alternatives to reduce water consumption”. Furthermore, he also recognized that cultural change is hard, especially in regions where water supply is not a main concern. He also added: “It is necessary to increase the awareness that reducing water consumption will not only result in a personal but a collective benefit”. On the other hand, one of the teachers who participated in the dry toilet building considered that the experience brought out the following aspects:

Team work, positive attitude, caring for each other and for the environment, positive thinking about the future of future generations, search for innovative and creative thoughts, importance of learning about our environment, reusing, and conservation.
She also mentioned:

This type of technology not only contributes to water-saving but also to create a culture of love towards the nature. In the aftermath of this experience, we started to work on the acquisition of habits among students and their families in order to change the mindset of waste and contamination. I am certain that if we aim at developing a cultural change, as well at incentivizing creativity and originality among our students, they will come up with excellent environmentally-friendly projects that will build up a better future for humanity and for the planet. In our school, we cultivated onions, carrots, coriander, lettuce, and radish using rainfall water.

She concluded by saying:

For the construction of the dry bathroom we used non-contaminating materials and reused those that do contaminate (tires, for instance). Teachers and students made the most of our knowledge in mathematics (direct and indirect measurements), language (not only verbal but corporal communication), geography (location), and biology (we observed different species in their natural environment and recognized biotic and abiotic factors). For me, one of the most important field of study that was brought during this experience was the one of Ethics: the fact of making students and teachers interested in a true problematic of the community – ‘the water in today’s world’ – is certainly a highlight of the project.

Conclusions
This paper contributes to the understanding of the dynamics of water saving through participatory design technologies. The results of the implementation of a device for the efficient use of the hydro resource in a Colombian rural region show the need of considering both social and hydrodynamic aspects for the design and building of the device. Additionally, the involvement of the communities in the decision-making processes, in the design of the technology and in its building is crucial for the replicability of the technology. Thus, to obtain successful results in the implementation of water-saving technologies, their design must consider the complexity of the relations between the stakeholders and technology to evaluate future implications, and it must be implemented in a participative way. PAWAME is a systemic methodology that could be developed in different rural context where the most important topic is to promote the adoption through the collective participation.

The implementation of a systemic methodology for the reduction of water consumption in rural areas is an example of how a transition from a rural region to a socially and environmentally sustainable system can be achieved and replied. Additionally, it promotes an interdisciplinary approximation that poses innovative and holistic questions based on a solid conceptual framework. Further studies could improve on this methodology, through the implementation of technologies in different rural and urban contexts.

Note
1. Political division within a municipality.

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Castelazo, A. (2014), “Mexicanos diseñan un dispositivo que ahorra agua en la regadera (Mexican designed a device to save water on shower)”, available at: https://codigoespagueti.com/noticias/hydroloop-inversion/


Further reading


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Sustainable development goals – an analysis of outcomes

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Abstract

Purpose – The concept of sustainability evokes a multiplicity of meanings, depending on the field. Some authors have criticized the concept for its vagueness. Notwithstanding this criticism, worldwide efforts to meet the sustainable development goals (SDGs) are in progress and are expected to yield results by 2030. This paper aims to address two issues and make two primary contributions. First, the concept of sustainability is revisited to develop its integrative understanding. This concept is built on systems thinking – specifically, on the concepts of synergy, emergence, recursion and self-organization. Second, an approach is developed to help determine whether the efforts being made towards the SDGs can be expected to be effective (i.e., whether the world can hope to soon be a system that self-organizes towards sustainability).

Design/methodology/approach – Based on the assumption that the SDGs and their respective targets are systemically interrelated, the data on the progress towards the SDGs are correlated and the outcome is analysed.

Findings – The emerging pattern of correlations reflected the systemic coherence of the efforts as an indication of self-organization towards sustainability. This pattern also revealed that the efforts are still spotty and that the systemic synergy has not yet taken place. This correlation approach to Brazil is then applied. The data about Brazil's progress towards the SDGs from the World Bank's Word Development Indicators (WDI) database are gathered. The outcomes indicated that Brazil as a whole cannot yet be seen as a self-organizing system that is evolving towards sustainability.

Research limitations/implications – To enable the calculation of the correlation matrix, the data series were not allowed to have missing values. Some of the WDI data series had many missing values and had to be eliminated. This unfortunately reduced the variability of the original data. In addition, the missing values in the remaining data series had to be calculated by means of interpolation or extrapolation. There are alternative algorithms to perform such functions. The impact of the interpolation and extrapolation of the missing values on the study, as well as the pros and cons of different algorithms, required investigation. It is important to remark that the WDI series was the only global and open data set that aligned with the SDGs.

Social implications – In Brazil, it is important to maintain the public policies that affect SDG 1-6, but it is necessary to develop policies geared towards SDG 12. Environmental goals also need more public policies (SDGs 14 and 15). To achieve this 2030 Agenda, much effort will be required for SDG 17, which is related to greater synergy through partnerships.

Originality/value – Three qualitatively distinct levels of efforts to sustainability are identified: individual, organizational and world activities. At the individual level, progress regarding sustainability depends on personal attitudes, including the willingness to abandon a self-centred lifestyle in favour of a more cooperative way of living and making decisions, and to embrace a new approach to ethics, which replaces self-interest by self-denial and self-sacrifice (de Raadt & de Raadt, 2014). At the organizational level, a paradox of the need to
internalize environmental and social costs into generic strategies and the sustainability strategy that involves core businesses are challenges for systems working towards sustainability. When it comes to global level, in this paper, the authors tried to make a contribution to push forward the frontier of knowledge by proposing an approach to understand whether the progress made towards the SDGs in the past 25 years indicates that the world is, after all, organizing for sustainability (Schwaninger, 2015).

**Keywords** Sustainability, Synergy, Recursion, Emergence, Self-organization, Systems thinking

**Paper type** Research paper

1. Introduction

The roots of the concept of sustainability can be traced far back in history. The ancient Egyptian, Mesopotamian, Greek and Roman civilizations experienced environmental problems, and the ancient Greek writers recommended practices that today would be called sustainable (Du Pisani, 2006). While the Oxford English Dictionary introduced the terms “sustainability” and “sustainable” in the second half of the twentieth century, they had already existed in other languages for centuries. The threat of a wood shortage, which was extensively used by in the eighteenth century, “stimulated a new way of thinking in favour of the responsible use of natural resources in the interest of the present and future generations” (Du Pisani, 2006, p. 85). This thinking is essential to the current understanding of sustainable development, which is defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland et al., 1987).

In spite of this early understanding, the concept of sustainability has changed over time. The discussion about sustainability was once a debate between the romantic, preservationist perspective and the utilitarian, conservationist approach; during the past three centuries, this has evolved to the current understanding that social and economic issues and environmental degradation must be addressed in conjunction (Robinson, 2004, pp. 371-372).

The result of this understanding has turned out to be “a curious combination of radical and reformist elements”, to use Robinson’s (2004, p. 372) terms. The radical aspect that Robinson referred to is the proposal that “the vast and complex issue of environmental deterioration” and “the equally vast and complex issue of human development and poverty” have to be resolved “simultaneously and in a mutually reinforcing way” (2004, p. 372). The reformist element lies in the suggestion that, to address environmental concerns, it is necessary to promote human development by increasing gross industrial activity across the world. In the so-called Brundtland report (Brundtland et al., 1987), the UN Commission on Environment and Development captured this combination of elements by proposing a balanced approach to development that could mitigate the risks of both underdevelopment and overdevelopment.

Discussions about sustainable development often present this phenomenon in three dimensions: economic, environmental and cultural. The concept of the “triple bottom line” introduced a vision of sustainability that connected social, environmental and economic dimensions (Elkington, 1998). These three dimensions of the sustainability vision were reinforced at the Sustainable Development Conference that was held in Johannesburg in 2002. Extensive efforts have been made to ensure that 2030 Agenda incorporates the cultural dimension into the sustainable development goals (SDGs; Soini and Birkeland, 2014).

The cultural aspect can be presented as a fourth dimension of sustainable development (Nurse, 2006) or embedded within its social dimension (Murphy, 2012). The 2030 Agenda is a
cross-cutting view of the cultural dimension for all 17 SDGs, bringing an integrated vision of this dimension across the 2030 Agenda (United Nations, 2017b).

As the discussion about sustainability developed, the concept became more complex and more challenging to define. Today, the term evokes a multiplicity of meanings, depending on the field. Some authors have argued that the concept of sustainability is so vague that it can be conveniently and opportunistically misinterpreted (Mebratu, 1998; Missimer et al., 2017a, 2017b; Robinson, 2004).

Other authors have responded that the vagueness and pluralism of the term’s definition is unavoidable and even preferable over a single, atomized conceptualization. These authors have argued that the concept of sustainability embodies many concerns and that it thus transcends disciplinary boundaries (Abson et al., 2017, p. 494; Missimer et al., 2017b, p. 2). They have seen value in sustainability as an integrative concept and as an interdisciplinary science (Missimer et al., 2017a, p. 7; Robinson, 2004, p. 378).

The discussion above does not reflect a solely theoretical concern, as it has consequences in practice. Some authors have pointed out that the improvements have been spotty (Schwaninger, 2015); that the magnitude and velocity of the changes have not been sufficient (Nunes et al., 2016); that the translation of sustainability from concept into practice is difficult (Taisch et al., 2015); and that it is also difficult to define a measure of sustainability performance (Nunes et al., 2016).

Mebratu (1998, p. 518) pointed out that one consequence of the effort to interpret sustainability according to the tenets of specific groups is that people have a narrow understanding of sustainability and are incapable of capturing the whole picture. Mebratu invited the scientific community to overcome the influence of institutional and group interests and to develop an understanding of sustainability, as this understanding is a prerequisite to achieving a sustainable world. We interpret the viewpoint of these authors as a claim that sustainability should be defined in terms of systems.

Independently of Mebratu’s concern, the efforts towards sustainability at the global level are centred on the SDGs (United Nations, 2017b). The deadline to achieve these goals is 2030.

The purpose of the present work is twofold. The first research question is conceptual and regards the nature and process of sustainability.

*RQ1*. How can we understand the concept of sustainability in a broad yet operational and integrative way? What process leads to sustainability at a global level?

The second research question is practical and refers to the effectiveness of the current efforts towards sustainable development.

*RQ2*. Has the progress made towards sustainable development at the global level resulted from integrated efforts that are leading the world (as a system) towards sustainability, or do the results seem to indicate that these efforts are isolated and that they can, therefore, produce only local and temporary improvements? In short, is the world self-organizing towards sustainability?

The latter question is at the heart of this research because it concerns the feasibility of achieving the SDGs by 2030 based on the efforts of autonomous agents, including business organizations, countries and individual citizens. Is the world really heading in that direction? Is there any hope that the SDGs can be met that quickly?

Sustainable development is a multi-dimensional concept that incorporates different aspects of society, seeking the environmental protection and the maintenance of natural capital to achieve economic prosperity and equity for present and future generations.
Sustainable development recognizes the inseparable link between people, the planet and wealth. Sustainable development is related to national and international policy development, making it the core element of the policy documents of governments, international agencies and business organizations (MEBRATU, 1998).

Thus, the term sustainability has emerged to address the issue of renewable resources, with a much greener connotation, and has been adopted by the ecological movement. The concept refers to the existence of ecological conditions necessary to support human life in a specific level of well-being through future generations, and this is ecological sustainability and not sustainable development (LÉLÉ, 1991).

Sustainability is a normative concept about how humans should act in relation to nature, and how they are responsible towards each other and future generations (AYRES, 2008).

Regarding RQ1, our intent here is not to provide a definitive definition of sustainability but rather to contribute to an interdisciplinary discussion of this concept based on systems thinking. In doing so, we automatically connect sustainability with systems practice, thus making available several systems methodologies, many of which are rooted in the solid ground of operational research. In other words, we find in systems thinking both a theoretical understanding and practical guidance – the latter of which, many of the aforementioned authors have noted, is missing in the concept of sustainability.

In terms of theoretical contribution, we develop in this paper an integrative understanding of sustainability that consists of three overall levels of human activity: individual, organizational and global. We consider sustainability in terms of systems concepts, such as recursion (Beer, 1979, 1985), emergence (Checkland, 1981), synergy (Beer, 1979) and self-organization (Malik and Probst, 1984; H. Ulrich, 1984). We based the idea of understanding sustainability in terms of levels on Beer’s viable system model (VSM) and its application in sustainable development, as promoted by de Raadt and de Raadt (2014) and Schwaninger (2015).

Addressing RQ2 necessitates data on the SDGs. Even though these goals were defined very recently, in 2015, the World Bank made available its World Development Indicators (WDIs; The World Bank Group, 2017) database, which can be used to assess nations’ current progress on the SDGs (World Bank Data Team, 2017). By correlating SDGs to each other – using the WDIs to measure the progress on each SDG in the past 25 years – and by applying multivariate data analysis (Johnson and Wichern, 2007) to those indicators, we attempted to figure out whether the efforts towards sustainability are in fact systemic or whether they are spotty. For the sake of illustration, we selected the Brazil data set from the WDI database.

Testing the correlations between SDGs rests on the assumption that the SDGs and their corresponding targets are systemically interrelated. The correlations between the goals are thus expected to reveal the coherence, or lack thereof, in the efforts that have been dedicated to fostering the development of the system as a whole. Thus, for instance, education and health goals are expected to be strongly positively correlated, and poverty is expected to be strongly negatively correlated with both education and health goals. In summary, the emerging pattern of correlation is expected to reflect coherent systemic relationships among goals.

In the following section, we developed the approach to sustainability based on systems concepts. In Section 3, we provide a description of the methodology that we envisaged to answer the question above. We describe the results in Section 4. In Section 5, we present the conclusions and discuss some final considerations.
2. Towards an understanding of sustainability based on systems thinking

2.1 System thinking and sustainability: a brief review

Some systems thinkers believe that the efforts to achieve sustainability at a global level have not been effective. Despite the well-intentioned declaration in the Brundtland Report, not much positive change has occurred: some localized improvements have been made, but the web of life continues to be disrupted (Schwaninger, 2015). In addition, the magnitude and velocity of these improvements have not been sufficient (Nunes et al., 2016). Furthermore, translating sustainability from concept into practice is difficult, so companies have had little guidance on how to define their manufacturing strategies and sustainability measures (Taisch et al., 2015). It is also difficult to define a measure of sustainability performance that encompasses all three aspects of the triple bottom line: economic, social and environmental (Nunes et al., 2016).

Business researchers have mainly focused on reducing the unsustainability of manufacturing systems and business models. Limited insight has been provided regarding how to create a manufacturing system that is both economically viable and, at a minimum, harmless; preferably, it would have positive or regenerative impacts on social and environmental systems (Taisch et al., 2015).

Two major questions remain unclear; they summarize the concerns about sustainability at two levels: first, “How [can humanity] create truly sustainable manufacturing systems” (Taisch et al., 2015); second, “How must humanity organize itself in order to develop sustainably?” (Schwaninger, 2015).

Systems thinkers claim that systemic and cybernetic approaches can help to address those questions. The complex issues within sustainability require a paradigm shift so that problems created at one level of thinking can be approached from a higher (or meta) level of thinking (Espinosa et al., 2008). Systems thinking can leverage such a paradigm shift.

Missimer et al. (2017a, 2017b) developed principles for social sustainability to further the development of the social dimension, which is the least developed dimension of sustainability. Missimer et al. based their principles on the complexity theory approach and developed an understanding of a social system as a complex adaptive system. This work is part of a broader effort to develop the framework for strategic sustainable development, which is intended to both provide a unifying structure for strategic sustainability work and serve as a systematic redesign that will promote societal compliance with the three principles of ecological sustainability.

Researchers have provided many examples of how best to approach sustainability problems by applying systems thinking and methodologies. System dynamics, for instance, have long been applied to various levels of human life: industries, cities and the world (Forrester, 1961, 1969, 1971).

Systems methodologies, such as soft systems methodology and critical systems heuristics, have also been applied. The latter, for instance, has been applied to an evaluation study of natural-resource-use appraisal in Botswana and to support participatory environmental decision-making among geographically distributed stakeholder groups in the remote, rural areas of Guyana (Ulrich and Reynolds, 2010, p. 248). In another application, both of the methodologies listed above were used to operationalize the concept of sustainability in a development project focused on Nordhavn, a new urban area of Copenhagen; this study had a particular focus on sustainable transport planning (Jeppesen, 2011).

Beer’s (1972, 1979, 1985) VSM, in particular, has been a source of inspiration for many authors. The VSM has been used as a conceptual tool for explaining sustainability (de Raadt and de Raadt, 2014; Espinosa et al., 2008; Schwaninger, 2015), as a reference model for...
manufacturing-strategy implementation (Taisch et al., 2015) and as a hermeneutical tool for establishing a self-organizing process that would restore the viability of Cloughjordan ecovillage, an Irish community founded on the principles of cooperation, democracy and sustainability (Espinosa and Walker, 2013). Schwaninger (2015) proposed a holistic structural framework based on the VSM to provide sustainable renewal. This framework covers several levels – individual human, organizational, local–regional and global. The VSM is a particularly suitable model for understanding sustainability because, as de Raadt and de Raadt (2014, p. 241) remarked, it “has been inspired from nature rather than built on utilitarian and positivist assumptions”; it “aims at sustaining life rather than making profits”; and it is proving useful “for managing a community with the common objective of preserving its long-term viability”.

However, accelerating the changes towards sustainability may not be a matter of just better defining the concept or ensuring better comprehension of it. De Raadt and de Raadt (2014) emphasized that sustainability issues reflect the lack of viability in the modern human lifestyle, and that the current worldview and approach to ethics are threats to the world’s natural and cultural aspects (de Raadt and de Raadt, 2014, p. 69). The authors also argued that a different way of thinking and new approaches to ethics and management are needed.

Ensuring the long-term viability of communities requires an integrated view of all aspects of life, including the ethical, aesthetic, juridical, operational, economic, social, epistemic, informational, historical, credal, psychic, biotic, regulatory, physical, kinetic, spatial, numeric and logical aspects (de Raadt and de Raadt, 2014, p. 197). These aspects are the backbone of multimodal systems thinking. In multimodal systems thinking, the underlying approach to management is built on the VSM.

Long-term viability, therefore, depends particularly on shifting the approach to ethics. People should not expect to achieve a sustainable world while insisting on getting more from the natural and social environments than they deliver to them. This means dismissing utilitarian ethics, which is centred on self-interest, and embracing a new approach to ethics that is based on self-denial and self-sacrifice. Ethics, as de Raadt and de Raadt (2014, p. 105) stated, is “the art of self-denial whereby we devote our life and work to serve and make up for the shortcomings of our fellow man hoping that someone will make up for our own shortcomings”.

2.2 The understanding of sustainability as an integrative concept based on systems

In this section, we addressed RQ1 of our work, which regards the understanding of sustainability as an integrative concept. We based this integrative concept of sustainability on systems concepts: recursion, emergency, synergy and self-organization.

2.3 Sustainability as a recursive process

The concept of recursion has its origin in a branch of mathematics called number theory and is widely applied in computer science to develop computer algorithms. A recursive definition is one that calls itself. The recursive definition of a factorial, for instance, illustrates the power of the concept to create synthetic definitions when an unlimited number of recursions are involved: factorial (n) = n * factorial (n – 1)

The systems concept is itself recursive when stated in this way: a system is a set of subsystems that interact. Each subsystem can itself be understood as a system, which, in turn, has its own interacting subsystems, and so on. Beer (1979, 1985) brought the concept of recursion to management science and proposed the VSM a general model of any viable system. The VSM is recursive.
Viability is the ability to maintain a separate existence (Beer, 1979, p. 113). It does not mean that a viable entity – whatever it is – must be able to live in isolation; rather, it must be able to survive as a singular entity and maintain its own identity and limits while in interaction with a complex and challenging environment. Based on cybernetic principles, Beer (1979, 1985) identified five essential functions that are necessary and sufficient for the viability of any organization:

1. Implementation of an essential purpose;
2. Coordination;
3. Operational monitoring and control;
4. Adaptive control; and
5. Supervisory control.

Thus, a system is viable if and only if it has all five of these functions. In addition, for a system to be viable, all of its subsystems must be viable. Therefore, each subsystem must also have all five functions (which are necessary and sufficient conditions for viability). Beer (1985, p. 2) thus established the recursive nature of viability; he argued that the term “recursion” was a reminder that he was not talking about a loosely coupled set of systems and subsystems, but about “an absolutely precise definition of viability”.

Beer’s insight can be transferred to sustainability. Figure 1, which Schwaninger (2015) elaborated on, provides a glimpse of sustainability as a multilevel, recursive process. Understanding sustainability as a recursive process means taking into account that, for a system to be sustainable, all of its subsystems must be sustainable. An organization, for instance, can be considered sustainable only when all of its essential processes are themselves sustainable. The advantage of this definition is that it does not leave room for

![Figure 1](image-url)

Source: Schwaninger (2015)
claims that cosmetic actions make an organization sustainable when they are actually concealing unsustainable processes.

The consequence of the recursive definition is that reaching sustainability at a global level requires integration of efforts across levels, including changes in individual attitudes and values, as well as in organizational strategies, governmental policies and international initiatives. Schwaninger (2015) described this multilevel understanding of sustainability as a precondition for sustainable development and explained how the principles embodied in VSM, such as autonomy and recursion, provide a powerful framework for pursuing sustainability.

The model in Figure 1 is not intended to provide only a structured view of sustainability; it has more profound implications. For instance, it implies connections across all levels, as part of a wholly integrated process. This is a truly integrative approach to sustainability. Beer (1979) explained that recursive logic consists of a process that runs through all levels of an organization and that has no limits. Beer saw the problems of his time as the result of managers cutting short this process by saying, for instance, “My responsibility ends here”. This attitude on the part of managers at all levels explained the problems that the world faced at that time: “dust bowls, pollution, city decay, starvation, violence, social revolution, and international warfare” (Beer, 1979, p. 312). Beer thus emphasized the importance of keeping this process running across recursion levels and without breaks. Non-business spheres of society are included in the sustainability equation, as shown in Figure 1, so the responsibility for keeping these recursive processes running falls on governors, as well as on managers. Not even individual citizens can escape their share of responsibility for these processes.

Thus, sustainability efforts at every level are needed to make the entire system a sustainable entity (i.e. to make the whole planet viable). Ignoring this recursive process and neglecting to responsibly contribute to it are among the root causes of all sorts of unsustainable situations. To paraphrase Beer (1985, p. 2), the concept of recursion is essential to an absolutely precise definition of sustainability.

### 2.4 Sustainability as an emergent property

The discussion in the previous section was intended to show that sustainability is not an accidental, isolated happening that takes place at a particular level. Sustainability at any level can be understood as an emergent property that results from the processes carried out on lower levels.

The concept of emergence is derived from the study of systems in terms of organized complexity (Checkland, 1981, p. 78). Organized complexity, as a general model, consists of a hierarchy of levels of organization, with the higher levels being more complex than the lower ones that comprise them. Each level is characterized by emergent properties that do not exist (and do not even make sense) at the lower levels. As an example, Checkland (1981) explained that the shape of an apple is indeed the result of processes that happen at the level of the cell, but it can hardly be explained using the language of that level. It is an “emergent property” that is usually expressed in a different language and using abstract concepts that belong to the “apple” level of recursion.

Similarly, sustainability at the global level emerges from processes that run at lower levels, including those of continents, countries, communities, organizations and even individuals, as illustrated in Figure 1.

### 2.5 Sustainability and synergy

Synergetic behaviour derives from mutual support between a system’s operational elements, with the intent to get “a higher total pay-off for the total system than the sum of
independently acting elements could produce, even if one or more of the elements is thereby rendered less profitable than it might be without invoking synergy” (Beer, 1979, p. 203). The manifestation of synergy depends on the existence of mutual interactions between a system’s elements. Totally independent elements do not comprise a system and thus cannot give rise to synergy. In this sense, the concepts of system and synergy are inseparable.

When efforts towards sustainability are isolated and sparse, they cannot interact and thus cannot create synergy. On the other hand, when efforts become so widespread across a certain recursion level that either the autonomous agents or the outcomes of their efforts start to interact, synergy can then be engendered, and the outcome can be expected to be more than the sum of the individual contributions. Proliferating initiatives is, therefore, a way to foster and take advantage of synergy, thus amplifying the magnitude and increasing the velocity of change.

If no synergy is created at any recursion level because the efforts are isolated, no emergent results will appear at the upper levels. The levels themselves will then remain separate with regard to sustainability, and the recursive process across levels will not take place. In other words, isolated efforts can never comprise a system and can never produce systemic outcomes, so they cannot make for a sustainable world.

2.6 Sustainability and self-organization

The structure depicted in Figure 1 is not intended to imply hierarchical control. Neither is it intended to presume that decisions emanate from a top-level entity. Coping with the challenges of sustainability requires agents – be they individuals, organizations or countries – to adjust and adapt to a large number of factors when facing complex issues in the context of a dynamic environment that is constantly changing in unforeseeable ways. Systems based on a command hierarchy are not effective at achieving their goals in such circumstances, as they cannot adapt rapidly enough. Polycentric systems, on the other hand, can process more information and adapt to a larger number of relationships. Polycentric systems are self-organizing and display considerably more adaptability; they, therefore, possess considerably more ability to overcome complexity (Malik and Probst, 1984, p. 110).

The fact that there is no centralized decision-making does not mean, however, that sustainability goals cannot be defined at the upper levels of recursion or that they cannot be enforced at lower levels to guide decision-making. As we noted above, autonomous agents that carry out isolated sustainability efforts do not comprise a system. Coordination of efforts is necessary to engender synergy. Although this does not entail a submission to command, it means that the lower recursion levels must accept some interventions from the upper levels (Beer, 1979, p. 203). Minimum intervention takes the form of synergistic planning, which means, in this context, the sustainability goals and their related targets.

Now, regarding Figure 1, imagine an ideal scenario in which the agents at the various recursion levels act autonomously but pursue the same sustainability goals. As they interact in a synergistic and coordinated fashion in the pursuit of those goals, they behave as a self-organizing system and are guided by the shared purpose of contributing to sustainability at a higher recursion level. In this ideal scenario, the individual agents are imbued with an ethical sense of self-denial and self-sacrifice on behalf of the greater good (de Raadt and de Raadt, 2014, p. 105), which aids in achieving sustainability at a global level. This is the ideal picture of a global system organizing itself for sustainability. Schwaninger (2015) stated that the viability of humanity in the long term depends upon its ability to organize for sustainability.
2.7 Towards a systemic understanding of sustainability

Schwaninger (2015, p. 937) proposed that “every viable system is sustainable, but that a sustainable system is not necessarily viable”. When Schwaninger asserted that a sustainable system is not viable, he was probably referring to the consequences of a vague concept of sustainability. Robinson (2004, pp. 373-374), for instance, warned that vagueness leaves room for stakeholders who are mainly concerned with their short-term political or business interests to take cosmetic actions intended to conceal unsustainable activities. Mebratu (1998, p. 493) warned that vagueness provides an opportunity for a variety of skewed definitions and interpretations that favour institutional and group prerogatives rather than those that promote traditional beliefs and practices.

What we propose here goes a step further. The understanding of sustainability as a systemic process, as presented in this section, suggests that sustainability and viability are two aspects of the same concept. Thus, a system is viable if and only if it is sustainable. After all, how can life on earth be viable otherwise? This seems to be in accordance with de Raadt and de Raadt (2014, p. 69, 233), who used the terms viable and sustainable interchangeably:

As Mebratu concluded:

If sustainability is to mean anything, it must act as an integrating concept. In particular, it is clear that the social dimensions of sustainability must be integrated with the biophysical dimensions. […] But it is also increasingly obvious that solutions that address only environmental, only social or only economic concerns are radically insufficient. What is needed is a form of interdisciplinary thinking that focuses on the connections among fields as much as on the contents of those fields; that involves the development of new concepts, methods and tools that are integrative and synthetic, not disciplinary and analytic; and that actively creates synergy, not just summation.

We have thus far provided a description of the nature and the process of sustainability to address Mebratu’s concerns. Systems thinking, by means of concepts such as synergy, emergence, recursion and self-organization, helps explaining sustainability as an integrative concept. Similarly, systems practice, which is implied from systems thinking, provides the tools and the integrative and synthetic methods that Mebratu called for.

We described sustainability at the global level as an emergent property that results from a recursive process initiated at the personal level. At each level, synergistic interactions take place among the autonomous agents at that level, allowing sustainability to emerge at the next level. Sustainability is thus leveraged level after level until it emerges as a property of a global system that is self-organizing and that has sustainability as its essence. Sustainability is a necessary and sufficient condition for viability at all levels. Sustainability thus defined remains a broad concept, but it is now backed up by systems thinking, which provides a sound theoretical basis for the interpretation and operationalization of that concept at any recursion level.

We thus have addressed RQ1 of our work and are left with RQ2. Are the current efforts enough to ensure sustainability’s emergence at the global level? Is the world self-organizing towards sustainability? In the next section, we prepare to address those questions by identifying the ongoing efforts towards sustainability.

2.8 Sustainability efforts at each level of recursion

The recursive definition of sustainability, as described in the previous section, suggests that a sustainable system can be understood as a set of recursive levels, as depicted in Figure 1. Each level of recursion has its own concerns, which are expressed in terms of language particular to that level.
2.9 Sustainability efforts at world level
At the global level, the challenges of sustainability are being addressed by means of international cooperation. The efforts to define a global agenda to deal with these sustainability challenges can be traced back to the 1972 United Nations Conference on the Human Environment, which was held in Stockholm. In consonance with what we have argued above, the conference, in its declaration, recognized that “Through ignorance or indifference we can do massive and irreversible harm to the earthly environment on which our life and well-being depend” (United Nations, 1972, p. 3). In this declaration, the conference proclaimed that defending and improving the human environment for present and future generations – in harmony with the traditional goals of peace and worldwide economic and social development – demand “the acceptance of responsibility by citizens and communities and by enterprises and institutions at every level, all sharing equitably in common efforts” (United Nations, 1972, p. 3). The recursive concept of sustainability, as described in the previous section, uses systems thinking to provide a rich interpretation of this declaration.

About a decade later, in 1983, the United Nations (UN) created the Commission on Environment and Development, also called the Brundtland Commission. In its report, which is officially entitled Our Common Future, the commission recognized the exceptional challenge stemming from the systemic changes that the goals demand (Brundtland et al., 1987, p. 305). The report included a definition of sustainable development that has become widely accepted and cited: “Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland et al., 1987, p. 27).

In 1992, the first United Nations Conference on Environment and Development, held in Rio de Janeiro, Brazil, developed the first agenda for Environment and Development. Of note, 20 years later at the Rio + 20 Conference, the member states agreed on a resolution known as The Future We Want whereby the participants reaffirmed their commitment “to making every effort to accelerate the achievement of the internationally agreed development goals, including the Millennium Development Goals (MDGs) by 2015” (United Nations, 2012, p. 1).

The MDGs (United Nations, 2017a) were adopted in September 2000 by 189 world leaders who attended the Millennium Summit at the UN headquarters in New York City. From 2000 to 2015, the eight MDGs became the overarching development framework for the world. Ban Ki-Moon, then the general secretary of the UN, reported that “The MDGs helped to lift more than one billion people out of extreme poverty, to make inroads against hunger, to enable more girls to attend school than ever before and to protect our planet” (United Nations, 2015, p. 3).

On 25 September 2015, the UN General Assembly adopted a new agenda to guide global action over the next 15 years. The 2030 Agenda for Sustainable Development consists of 17 SDGs and 169 associated targets (United Nations, 2017b). The SDGs focus on five themes: people, planet, prosperity, peace and partnership. This new agenda builds on the achievements of the MDGs and extend their scope.

2.10 Sustainability efforts at organizational level
Unlike their predecessor, the SDGs clearly link with efforts at the level of business organizations. As stated in the SDG Compass, the goals “explicitly call on all businesses to apply their creativity and innovation to solve sustainable development challenges” (GRI, UN Global Compact, & WBCSD, 2015, p. 4). The SDG Compass was launched in September 2015 at a business event at the UN headquarters in New York (Global Reporting Initiative, 2015).
The SDG Compass (GRI et al., 2015) was intended to help companies align their strategies with the SDGs, and measure and manage their impacts, so as to maximize their contribution to the goals.

For the first time, a sustainability initiative at a global level of recursion can be connected to efforts at a lower level, in this case, the business organizations. Furthermore, it represents an opportunity to establish a recursive process across all levels, as companies represent one way to reach individuals in the society, and to expedite the achievement of sustainability goals at a global level.

To achieve this, the declared vision and the mission of firms must include sustainability as a primary concern. At that level, for instance, the organization’s vision and strategy matter that will guide the organization’s decisions, such as its approach to promote consumption through marketing actions.

A different way of thinking, as proposed by de Raadt and de Raadt (2014), must include a review of traditional business strategies. Generic strategies such as Porter’s (1985) cost leadership, for instance, which was so widespread by business strategists at the turn of the millennium, needs to be revisited and reviewed. The managers’ interpretation of such a strategy, and particularly the means that are used to achieve the lowest price, must be reconsidered to include social and environmental costs, if one intends to avoid slavery and labour abuses, and the depredation of nature.

At the organizational level, the Responsible Care initiative maintained by the global chemical industry is noteworthy (American Chemistry Council, 2013; The International Council of Chemical Associations, 2005). Responsible Care is an environmental, health and safety initiative that supports cooperative and voluntary actions with government and other stakeholders. Through Responsible Care, the International Council of Chemical Associations has undertaken actions that are consistent with the environmental principles of the UN Global Compact.

2.11 Sustainability efforts at personal level

At the personal level, small things matter. These include aspects such as the personal attitude towards the usage of water and energy and consumption habits. That level seems distant from the planetary level where one can feel disheartened to start an individual effort. But, like the proverbial hummingbird attempting to put out a forest fire with water she carried in her beak, everyone must be encouraged to take his or her share of the responsibility. This is the level where a new approach to ethics, which replaces self-interest by self-sacrifice, as suggested by de Raadt and de Raadt (2014), must start, because efforts at the individual level, when recursively summed up, may result in significant contributions to sustainability at the upper levels of recursion.

3. Methodology

In the introduction, we made the point that sustainability is important as an integrative concept. In the previous section, we developed such an integrative understanding of sustainability by interpreting the world as a self-organizing system with multiple recursion levels. The model conveys the idea that the improvements expected at the global level depend on the efforts undertaken at the lower levels of recursion. We then identified the SDGs and the SDG Compass as ongoing efforts towards sustainability. We also pointed out the need for a shift in the dominant approach to ethics.

Now we are prepared to address the second research question of our work. Is there hope that ongoing efforts are leading the world system towards sustainability, or do the outcomes seem to indicate that efforts are still isolated and can, therefore, produce only local and
temporary improvements? In other words, is the world, as a system, self-organizing for sustainability, or are the efforts at each recursive level enough to create synergy and make sustainability emerge as an intrinsic property of the world?

To investigate that question, we need to measure the progress made towards sustainability at a global level; to do so, we need data on that progress, and we need a method. Regarding current progress, the SDGs seem to be an obvious choice. Investigating whether the progress that is being made towards the SDGs is the result of an integration of efforts that is leading to a sustainable world or not is appealing.

Because the definition of the goals dates to 2015, no historical data were directly collected for the SDGs. However, The World Bank Group (2017) provided the data series for its primary collection of WDIs. These WDIs are the most current and accurate global development data available, compiled from officially recognized international sources. They include national, regional and global estimates from 1990 through 2015. Experts from the World Bank selected a set of WDIs for each of the 17 SDGs and corresponding targets. A dashboard presents data from the WDIs that help monitoring the SDGs.

To calculate the correlation matrix of the SDG-related data series, a multivariate method was chosen. Sterman (2000) explained that, even though correlations among variables do not represent the structure of the system, they represent past behaviour and emerge from the behaviour of the system. The intent was to analyse the correlations between the SDGs and assess whether those correlations corroborated the idea that the progress made towards the SDGs was the result of an integration of efforts that is leading to a sustainable world, or whether they conveyed the idea that the efforts were isolated.

The data analysis involved the following steps:

1. removal of data series with too many missing values (fewer than 20 values);
2. interpolation and/or extrapolation of missing values in the remaining data series that were still incomplete;
3. scaling of data
4. applications of multivariate data analysis:
   a. principal component analysis (PCA) to reduce the number of variables; and
   b. factor analysis to determine which factors were responsible for the data variability
5. calculation of the correlation matrix for the reduced data set.

The steps were programmed in R language (Crawley, 2013), which is a programming language and environment for statistical computing and graphics. It is an alternative implementation of the S language and environment developed by John Chambers and his team at Bell Laboratories. R is a GNU project and is available as free software under the terms of the GNU General Public License. R is an integrated suite of software resources that, besides the programming language itself, includes data handling and storage facilities, calculations on vectors and matrices, a variety of tools for data analysis, including graphical analysis, and presentation of data (The R Foundation, 2018).

We used RStudio (RStudio Inc, 2016) to support R programming and run the data analysis. RStudio is an integrated development environment that supports R programming. It includes a console, a syntax-highlighting editor, code execution and debugging, among several other features. It is available both in open source and commercial editions (RStudio, 2018).

The raw data series for all the WDIs, with data from 1990 to 2015 for several countries, were downloaded from the World Bank’s website to a Microsoft Excel spreadsheet. Data series for Brazil were retrieved from the raw data spreadsheet by means of R programming.
resulting in 291 data series. Brazil was chosen, in principle, because it is the native country of the authors. Also, it is an appropriate choice for the exercise in question because it is a country with a continental dimension that faces significant challenges regarding sustainability.

4. Results
The WDI s for Brazil were selected, grouped into SDGs according to the mapping suggested by the World Bank’s experts and sorted by SDG. As an example, Table I shows the mapping of Target 1 and Target 2, under Goal 1, onto the WDIs. The complete mapping of the SDGs onto the WDIs is not shown here for lack of space (it involves 263 WDIs).

A few SDG targets were mapped onto one WDI. Other SDG targets were mapped onto several WDIs. This step resulted in 263 data series. There were several data series that rendered useless for the purpose of this study because they had too many missing values. Any data series with less than 20 valid values was removed. Only 109 data series that had at least 20 values were kept.

There also were redundant data series, such as data series for men, women and the combination of both; or data series for rural areas, urban areas and the combination of both. Such combined data series were removed to eliminate redundancy. After the removal of redundant data, 94 data series were left.

The remaining data series had a few missing values, either in the middle or at the beginning or end. The intermediate missing values were interpolated. Missing values at the beginning or the end of the data series were inferred by extrapolation. A combination of “na.aprox” and “na.locf” functions from the zoo library of the R language was used to perform the extrapolations. The na.aprox function was used to replace each missing value in the middle of a data series with interpolated values. Then, the na.locf function was used to fill in the missing values at the beginning of a data series by carrying backward the first available observation and to fill in the missing values at the end of a data series by carrying forward the last available observation. Once the data series were complete, i.e. without any missing values, the data were scaled by using the scale function from the R language.

Table II shows the correspondence between each SDG and the 94 WDI data series after the data treatment.

The number of variables (data series) was still too high to allow a study of the correlations. To reduce the number of variables, we performed a PCA for each SDG. The PCA allowed us to aggregate data for several WDI series into fewer SDG components.

However, before performing a PCA, for the sake of coherence, many WDI data series had to have their signs switched (i.e. it had to be multiplied by –1) to make them consistent with the meanings of their corresponding SDGs. Thus, for instance, the WDI index SI.POV.

<table>
<thead>
<tr>
<th>SDG targets</th>
<th>WDI indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target 1.1: By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day</td>
<td>Poverty headcount ratio at $1.90 a day (2011 PPP) (% of population)</td>
</tr>
<tr>
<td>Target 1.2: By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions</td>
<td>Poverty headcount ratio at national poverty lines (% of population)</td>
</tr>
</tbody>
</table>

**Table I.** Example of mapping of SDG 1 and Targets 1 and 2, onto WDI
<table>
<thead>
<tr>
<th>#</th>
<th>Sustainable development goal</th>
<th>+/-</th>
<th>WDI data series code</th>
<th>Reduced data set</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>No poverty</td>
<td>-</td>
<td>SL.POV.DDAY</td>
<td>SDG01</td>
</tr>
<tr>
<td>02</td>
<td>Zero hunger</td>
<td>-</td>
<td>SN.ITK.DEFC.ZS</td>
<td>SDG02.PC1</td>
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<tr>
<td></td>
<td></td>
<td>+</td>
<td>AG.YLD.CREL.KG</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>EA.PRD.AGR.LKD</td>
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<td>-</td>
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<td>SDG03.PC1</td>
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<tr>
<td></td>
<td></td>
<td>-</td>
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<td>SH.IMM.HEPB</td>
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<td>-</td>
<td>SP.ADO.TFRT</td>
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<td>04</td>
<td>Quality education</td>
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<td>EG.EGY.PRIM.PP.KD</td>
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<td>+</td>
<td>NY.GDP.PCAP.KD.ZG</td>
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</table>

**Table II.** Reduction of the data set by means of principal component analysis (continued)
DDAY (poverty headcount), which is a measure of the tendency towards poverty, had its sign switched to comply with SDG 1, which requires a measurement of the tendency towards No Poverty (refer to Table II). In other words, instead of measuring how much the poverty is decreasing, we were interested in measuring how much No Poverty is increasing.

<table>
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<th>WDI data series code</th>
<th>Reduced data set</th>
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<td>SP.URB.GROW</td>
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</tr>
<tr>
<td>15</td>
<td>Life on land</td>
<td>+</td>
<td>AG.LND.FRST.K2</td>
<td>SDG15.PC1</td>
</tr>
<tr>
<td>16</td>
<td>Peace, justice and strong institutions</td>
<td>+</td>
<td>GC.TAX.TOTL.CN</td>
<td>SDG16.PC1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+</td>
<td>GC.TAX.TOTL.GD.ZS</td>
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<tr>
<td></td>
<td></td>
<td>+</td>
<td>NE.EXP.GNPS.ZS</td>
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<td>NY.GDP.MKTP.CD</td>
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<td>DT.TDS.DPPF.XP.ZS</td>
<td>SDG16.PC24</td>
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<td>SDG16.PC25</td>
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<td></td>
<td></td>
<td>+</td>
<td>IP.PAT.RESD</td>
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<td></td>
<td></td>
<td>+</td>
<td>IT.NET.USER.ZS</td>
<td>SDG16.PC27</td>
</tr>
</tbody>
</table>

Table II.

94 variables 22 variables
By switching signs in this way, we eliminated mismatches between the meaning of the WDIs and the meaning of their corresponding SDGs. Furthermore, this procedure helped make the interpretations of the correlations more straightforward.

As Table II shows, SDGs 1, 5 and 10 corresponded to a single WDI data series. They were kept as they were. SDGs 13 and 16 had no data left. Their corresponding WDI data series were removed because they had many missing values.

All other SDGs corresponded to two or more WDI data series. SDG 3, for instance, corresponded to ten data series, and SDG 17 corresponded to 29 data series. For each of those SDGs, a PCA was performed -- and the corresponding scores were calculated -- by using the “prcomp” function from the stats library of the R language -- to be used in the place of the original expanded data. The prcomp function was used to perform a principal component analysis on the data set by means of a singular value decomposition of the data matrix, not by using the eigen or covariance matrix. This is generally the preferred method for numerical accuracy. A factor analysis was also performed to determine what factors were responsible for the data variability. By doing so, the number of variables (data series) was reduced, as shown in the last column of Table II. After that procedure for each SDG, the data set was reduced to 22 data dimensions.

The prefix “PC” was appended to the names of the data series to denote that they were the result of the principal component analysis. Most of the SDGs were reduced to a single principal component, with the prefix “PC1”. The only exceptions were SDGs 8, 9 and 17, for which three, two and four principal components were necessary, respectively, to convey the variability of the original data. No principal components had to be calculated for the SDGs with no prefixes, as their corresponding data consisted of a single data series.

The correlation matrix for those 22 dimensions was then calculated using the “cor” function from the stats library of the R language. Figure 2 shows the correlation matrix that
was generated using the “corrplot” function from corrplot library of the R language. The area and the intensity of the colour of the ellipses corresponded to the magnitude of the correlation coefficient: the larger the area and the more intense the colour, the larger the correlation. The slope of the ellipses’ axis stands for the signal of the correlation coefficient: slope to the right (\( \uparrow \)) stands for a positive correlation, whereas slope to the left (\( \downarrow \)) stands for a negative correlation.

It is important to call attention to the meaning of these correlations. They are not correlations between random variables but rather between data series. All the data series have the same time basis. The values of the series were aggregated by year. What these correlations express, by considering its mathematical nature, is a correlation between tendencies:

- A high positive correlation means that the data series exhibited similar tendencies with time, i.e. as one index increased, the other tended to increase, and vice versa.
- A high negative correlation means that data series exhibited opposite tendencies with time, i.e. while one index increased, the other tended to decrease, and vice versa.
- A low correlation means that the tendencies did not seem to have any relation.

High positive correlations were expected, for instance, between health and education, whereas high negative correlations were expected, for instance, between education and poverty or between poverty and health. A negative correlation between health and education goals might be an indication that investments are not enough to cover both goals and that oscillation is taking place as efforts are allocated to either one or the other. This would indicate a need to dig up the root causes of such oscillations in the lower levels of recursion. An emerging pattern of correlations that seems highly coherent might be interpreted as a signal of synergy and self-organization towards sustainability. Similarly, a highly incoherent pattern of correlations might be an indication that efforts are spotty, uncoordinated and not enough to give raise to synergy.

It is assumed that the transients that are typical in the dynamic behaviours of systems – such as undershoot, overshoot and high-frequency oscillations – do not significantly affect the correlations. The fact that the data series are aggregate in a yearly basis is assumed to eliminate such high-frequency transients, so as to smooth the tendency curves.

In addition to the correlations matrix, we performed a factor analysis using the “fa” function from the psych library of the R language. The factor analysis was performed on the correlations matrix by choosing the minimum likelihood method with a varimax rotation. The result of the factor analysis is reported in Table III, where “MLi” is the factor loading, \( h^2 \) is the communality and \( u^2 \) is the uniqueness. The number of factors (4) corresponds to the number of eigenvalues that are greater than 1. They explain 93 per cent of the variability of the data. The first eigenvalue alone explains 58 per cent of the variability of the data.

The correlation matrix indicates a very strong correlation among the first six dimensions. A high correlation assumed by the first six SDG dimensions seems to attest that there is a relevant relation between the SDGs progress along those 25 years. We did not build a dependency model in a way that exploratory correlations could arise. The results showed that efforts existed and they were strongly correlated in the cases of “No poverty”, “Zero Hunger”, “Good health and well-being”, “Quality education”, “Gender equality” and “Clean water and sanitation” dimensions. In fact, the tendency curves for SDGs 1-6 in Figure 3 illustrate what has been described. Data, thus, show a subsystem of the entire system that
may be self-organizing towards meeting the goals. This subsystem can be characterized as men and women, with no hunger, in good health and sanitary conditions, who can both enjoy and contribute to positive results as they have access to education of good quality.

In addition, SDGs 1-6, 9, 11, 14 and 15 seem to comprise a group of systemic results. Their results add to the first axis of relation in the “Industry, Innovation and Infrastructure”, and “Sustainable Cities and Communities” extends to a second axis of results in which educated men and women, in good health and sanitary conditions, that live in sustainable cities and have access to technology work are a point of change in consistent actions over time.

Table III.

<table>
<thead>
<tr>
<th>22 dimensions</th>
<th>Adopted description</th>
<th>ML1</th>
<th>ML3</th>
<th>ML2</th>
<th>ML4</th>
<th>h2</th>
<th>u2</th>
</tr>
</thead>
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<tr>
<td>SDG01</td>
<td>No poverty</td>
<td>0.95</td>
<td>0.10</td>
<td>0.22</td>
<td>-0.09</td>
<td>0.97</td>
<td>0.03</td>
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<td>SDG02.PC1</td>
<td>Zero hunger</td>
<td>0.99</td>
<td>0.04</td>
<td>0.02</td>
<td>0.06</td>
<td>0.99</td>
<td>0.01</td>
</tr>
<tr>
<td>SDG03.PC1</td>
<td>Good health and well-being</td>
<td>0.94</td>
<td>0.29</td>
<td>0.12</td>
<td>0.08</td>
<td>0.99</td>
<td>0.01</td>
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<td>SDG04.PC1</td>
<td>Quality education</td>
<td>0.93</td>
<td>-0.25</td>
<td>-0.02</td>
<td>0.10</td>
<td>0.93</td>
<td>0.07</td>
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<tr>
<td>SDG05</td>
<td>Gender equality</td>
<td>0.92</td>
<td>0.19</td>
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<td>-0.05</td>
<td>0.89</td>
<td>0.11</td>
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<tr>
<td>SDG06.PC1</td>
<td>Clean water and sanitation</td>
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<td>0.06</td>
<td>1.00</td>
<td>0.00</td>
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<td>SDG07.PC1</td>
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<td>0.19</td>
<td>0.51</td>
<td>0.58</td>
<td>0.99</td>
<td>0.02</td>
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<td>SDG08.PC1</td>
<td>Decent work and economic growth</td>
<td>0.17</td>
<td>0.81</td>
<td>0.43</td>
<td>0.11</td>
<td>0.88</td>
<td>0.12</td>
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<td>-0.10</td>
<td>0.07</td>
<td>0.91</td>
<td>0.09</td>
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<td>0.01</td>
<td>0.07</td>
<td>-0.39</td>
<td>0.35</td>
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<td>SDG09.PC1</td>
<td>Industry, innovation and infrastructure</td>
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<td>-0.13</td>
<td>-0.10</td>
<td>-0.17</td>
<td>1.00</td>
<td>0.01</td>
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<td>0.18</td>
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<td>0.80</td>
<td>0.35</td>
<td>0.91</td>
<td>0.10</td>
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<td>SDG10</td>
<td>Reduced inequalities</td>
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<td>0.07</td>
<td>0.77</td>
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<td>-0.58</td>
<td>-0.22</td>
<td>0.71</td>
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<td>Life bellow water</td>
<td>0.98</td>
<td>0.11</td>
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<td>0.06</td>
<td>0.97</td>
<td>0.03</td>
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<td>SDG15.PC1</td>
<td>Life on land</td>
<td>0.97</td>
<td>0.21</td>
<td>0.12</td>
<td>0.04</td>
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<td>0.00</td>
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<tr>
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<td>Partnerships for the goals</td>
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<td>0.09</td>
<td>-0.13</td>
<td>-0.01</td>
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<td>0.11</td>
<td>0.17</td>
<td>0.74</td>
<td>0.59</td>
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Figure 3.
Scaled tendency curves for SDG 1-6
Moreover, results from SDGs 1-10 correlations show medium to high positive correlation, which means that Goals 1 (No Poverty), 2 (Zero Hunger), 3 (Good Health and Well-Being for people), 4 (Quality Education), 5 (Gender Equality), 6 (Clean Water and Sanitation), 7 (Affordable and Clean Energy), 8 (Decent Work and Economic Growth), 9 (Industry, Innovation, and Infrastructure) and 10 (Reduced Inequalities) are tending to have coherent results. They have exhibited consistent behaviours, reinforcing their positive effects on each another. The third factor, or axis, represents a broader conception, according to which energy, decent work and reduced inequalities emphasize the power of the first two axes.

When it comes to Goals 14 and 15 (Life below Water and Life on Land), there is also a strong positive correlation exposing that life conditions perform the same behaviours of the Axes 1 and 2, as confirmed on communality results of the factor analysis (Table III). It seems like these two aspects are being neglected in comparison with efforts on other dimensions and are thus producing positive impacts on overall results. The behaviours of these two dimensions or Axis 4 deserve deeper investigation to explore the cause-and-effect dynamic.

Therefore, Goals 1-6 (Axis 1), 1-10 (Axis 3) and 14 and 15 (Axis 4) are considered the group that presents conjoint growth with positive consistent results over the years.

On the other hand, a negative correlation in the case of the SDG 9 dimension (Industry, innovation and infrastructure) was surprising, meaning that the increase of technology and markets is not necessarily aggregating to systemic progress. The dimension alone does not provide a meaningful correlation among others, especially about CO2 emissions. When opening the data of SDG 9, it is clear that economic data (and related variables) described in Table II present different behaviours than that of the CO2 emission index. This dimension needs further investigation to understand its impact.

According to the matrix, SDG 17 (Partnership for the Goals) has a negative or weak correlation with almost all other variables, making clear the difficulty of integrating efforts to sustainability as a viable system. Beer (1979) predicted that fragmented efforts are not efficient to system development.

In addition, SDG 12 (Responsible Production and Consumption) has a negative correlation with almost all other SDG indicators. It means that efforts carried out in lower recursion levels may not be linking to overall results. The organization’s efforts to promote cleaner production and more conscious consumption do not seem to be presenting any systemic impact.

In summary, the efforts in Brazil seem to be more centred on social dimensions of sustainability, such as education, health and eradication of poverty. Economic dimensions, such as industry, innovation and investments do not appear to be presenting promising results. The results on the ecological dimensions are not encouraging either.

Four axes of data behaviour and systemic change tendencies were identified through the factor analysis and multivariate regression. Axis 1 (Goals 1-6), Axis 2 (Goals 1-6, 9, 11, 14 and 15), Axis 3 (Goals 1-10) and Axis 4 composed of SDG 14 and 15 are the understandings of the overall data results during the 25 years of progress. The first factor (ML1) in Table III seems to indicate that most goals are synergistically interrelated.

5. Final considerations
In this paper, we proposed the understanding of sustainability as an integrative concept, more specifically as a systemic concept. The importance of systemic understanding of sustainability can be stated on the basis of the contribution that systems thinking and systems practice can provide to make sustainability more scientific – if we consider the contributions that a cybernetic insight can bring (Beer, 1979, 1985; Forrester, 1961, 1969, 1971) – more participative (Checkland, 1981, 2000), more democratic (Ulrich, 1983; Ulrich

Four main aspects could represent the linkage between systems and sustainability: recursion (Beer, 1979, 1985; Schwaninger, 2015), emergence (Checkland, 1981), synergy (Beer, 1985) and self-organization (Malik and Probst, 1984; H. Ulrich, 1984). Recursion is an aspect of systems thinking that allows people to understand and explain the complexity behind sustainability. It also allows people to see sustainability as an organized set of levels, one on top of the other, the higher levels being progressively more complex than the lower ones that produce them. The concept of emergence states that, in this complexity organized as layers, sustainability at a certain level of organization relies on processes that run in the lower levels. At each level, the manifestation of synergy depends on the existence of mutual interactions between autonomous agents at the respective levels. Independent efforts on the part of those agents cannot give rise to synergy, cannot make desired sustainability to emerge at the upper levels and cannot recursively link all processes across the levels. This process is not expected to be controlled by a centralized source of command, but it is expected to work as a self-organizing system, whereby autonomous agents work synergistically in the pursuit of sustainability.

Three qualitatively distinct levels of efforts to sustainability are identified: individual, organizational and world activities. At the individual level, progress regarding sustainability depends on personal attitudes, including the willingness to abandon a self-centred lifestyle in favour of a more cooperative way of living and making decisions, and to embrace a new approach to ethics, which replaces self-interest by self-denial and self-sacrifice (de Raadt and de Raadt, 2014). At the organizational level, a paradox of the need to internalize environmental and social costs into generic strategies and the sustainability strategy that involves core businesses are challenges for systems working towards sustainability. When it comes to global level, in this paper, we tried to make a contribution to push forward the frontier of knowledge by proposing an approach to understand whether the progress made towards the SDGs in the past 25 years indicates that the world is, after all, organizing for sustainability (Schwaninger, 2015).

The proposed approach has been demonstrated by applying it to data for Brazil. The outcomes showed mixed results. Efforts in Brazil seem to be more centred on social dimensions of sustainability. For those dimensions, the correlations seem to indicate that systemic self-organization might be taking place. This means that there seems to be a subsystem of the whole that is consistently and coherently making progress towards meeting the goals and, possibly, self-organizing towards sustainability. However, for the economic and the ecological dimensions, the results do not show such systemic consistency.

The vision of the SDGs as an integrating concept from a systemic perspective is the main contribution of this paper. As we mentioned above, earth’s long-term viability requires an integrated view of all aspects of life. Our results reinforce the understanding that public policies are needed to increase adherence to the SDGs. At the industry recursion level, public policies that encourage adherence to the UN Global Compact are important to foster greater synergy and better results.

In Brazil, it is important to maintain the public policies that impact Goals 1-6, but it is necessary to develop policies geared towards Goal 12. Environmental goals also need more public policies (Goals 14 and 15). To achieve this 2030 Agenda, much effort will be required for Goal 17, which is related to greater synergy through partnerships.

In conclusion, the correlations seem to provide a rough indication that Brazil as a whole is not yet self-organizing as a system towards sustainability, even though significant
progress has been made in the social dimensions. The explanations for these outcomes must be further investigated at the lower level of recursions.

If humanity is to build a sustainable world over the next decades – as implied in the SDGs – and if de Raadt and de Raadt (2014) were correct that, to achieve sustainability, a shift in the dominant approach to ethics is needed – then major global changes are imminent in the ways cities are organized, in the ways people do business and in the ways people think and live. The recursive model of sustainability, as described in this work, suggests that, by proliferating initiatives, governors and managers can wisely take advantage of synergy and recursion to amplify the magnitude and increase the velocity of these changes.

6. Research limitations
To enable the calculation of the correlation matrix, the data series were not allowed to have missing values. Some of the WDI data series had too many missing values and had to be eliminated. This unfortunately reduced the variability of the original data.

In addition, the missing values in the remaining data series had to be calculated by means of interpolation or extrapolation. There are alternative algorithms to perform such functions. The impact of the interpolation and extrapolation of the missing values on the study, as well as the pros and cons of different algorithms, required investigation. It is important to remark that the WDI series was the only global and open data set that aligned with the SDGs.

7. Future research
Regarding the method used in this research, because the data analysis was programmed in R language, it will allow other countries or even entire continents for which the WDIs are available to be analysed by running the program. In this way, the study can be repeated for different countries and continents, and the results can be compared. In addition to the findings regarding the progress towards the SDGs for different countries, such an exercise can be useful to refine the method developed in this work and to ensure its validity.

The conclusions presented for Brazil are based on aggregate data. They represent an overall result for the entire country. As Brazil is a large country comprising different regions with very contrasting characteristics, these results may not reflect the reality of a particular region of the country. Further investigation at the lower levels of recursion is necessary to understand how the special characteristics of particular regions of the country contribute to the underlying dynamics that produce the emergent results found at the aggregate level. Such an investigation can also be extended to include the contributions added by the business organizations and individual citizens.

Regarding the application of the VSM, its design and diagnosing features have not been fully explored in this work. It can be used to further investigate the lower levels of recursion. At each level of recursion, an effort to identify and describe the subsystems of the VSM might be an interesting alternative to both identify and investigate issues related with autonomy (S1), coordination (S2), synergy (S3), adaptability (S4) and vision (S5).

Other aspects to consider include homeostasis (Chrousos and Gold, 1992, p. 2) and the dynamic capability of adaptation of sustainability systems along the same time period.
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Abstract

Purpose – The purpose of this paper is to highlight the applicability of integrated simulation models for national development planning to different issues and contexts. Specifically, the authors describe one such model, the Millennium Institute’s T21 model, which is used to support planning in various countries, and explore in detail the case of Swaziland to demonstrate the model’s usefulness at different levels in the planning process.

Design/methodology/approach – Integrated sustainable development planning models using the system dynamics (SD) modeling method have been designed to help overcome these obstacles and support decision-makers in the assessment of alternative policies. Such models are laboratory replicas of the critical mechanisms driving development in a country while being grounded in the historical data available. They can be used to perform simulation-based policy experiments that are otherwise impossible in the real world.

Findings – The proposed approach has facilitated the reporting on the Millennium Development Goals (MDGs), as well as on the cross-sector long-term ex ante evaluation of the country’s “Economic Recovery Strategy” and a proposed “Fiscal Adjustment” policy. These assessments provided essential information for improving the quality of the decisions made. Such information cannot be obtained by the application of purely economic models or sectoral tools, that are not including the fundamental feedback structures that shape development in the long run and determine its sustainability.

Research limitations/implications – The new generation of global long-term Sustainable Development Goals (SDGs) covers a far broader range of issues and indicators than the MDGs. The T21-Swaziland model only offers a limited subset of such issues, and future research will focus on achievements and challenges in expanding its scope to encompass the SDGs.

Practical implications – The T21 model has become one of the fundamental planning instruments of the country, and it has been used to evaluate national planning documents and other suggested strategies with respect to whether they are sufficient for reaching the long-term goals. Such information is then used as a basis for revision of development plans and adoption or rejection of suggested policy packages.

Originality/value – The MDGs (and their expanded follow-up, the SDGs) have been important steps toward better governance, as they quantify key indicators of development and thereby allow for an evaluation of the degree to which these quantified aspirations are actually achieved. In addition to such hind-sight evaluations, ex ante evaluations are equally important for improving the quality of the decisions made. The authors propose and test a tool to support such type of evaluation, supporting integrated planning and model-based governance.

Keywords Millennium development goals, Sustainable development goals, Ex ante policy assessment, Integrated planning, Model-based governance, Policy synergy

Paper type Technical paper
1. Introduction
Governance and “bad governance” are terms increasingly used to identify aspects of how our institutions work that are especially important to facilitate, or otherwise hinder, development. Although a variety of definitions of governance exists, in a broad sense public governance has to do with the way the executive power (i.e. the government) is managed. The concept of governance is tightly connected with government’s ability to make and enforce rules and to deliver services (Fukuyama, 2013). Within such framework, the ability of the government to establish effective long-term plans toward a country’s sustainable development is a key component of good governance.

Effective long-term planning is especially difficult in highly dynamic development contexts. The ex ante evaluation of policy impacts is valuable to deal with uncertainties in such contexts and should go well beyond measurement of direct impact of a single policy on a key performance indicator in a given sector (e.g. an improvement of enrollment in secondary education), to consider the complex, system-wide ripple effects that the combination of policies in place bring about. Effective planning thus requires the use of tools that allow designing effective integrated policy packages and strategies, estimating their potential impact and supporting their monitoring and evaluation.

With the UN Conference on Environment and Development in Rio de Janeiro in 1992 (United Nations General Assembly UN, 1992), the Millennium Declaration in 2000 (United Nations General Assembly UN, 2000) and the most recent call for a set of universally recognized Sustainable Development Goals (United Nations General Assembly UN, 2015), there has been an increasing recognition of the integrated social, economic and environmental nature of development and of the need of integrated solutions. Unfortunately, national planning is often hindered by a lack of integration between different organizational units of government (Marcus et al., 2006). While thematic specialization within the framework of separate ministries is an understandable consequence of different problem areas and the limited cognitive ability of human beings, this somewhat segregated approach makes it difficult to gain a “birds-eye” view that recognizes the interconnectedness of various development issues. Tools that elicit and visualize these interconnections play a key role in enhancing mutual understanding and integration of ministries to reach common goals.

Another common weakness of national planning systems is the lack of harmonization between short and long-term plans. As a result of the limitations of tools commonly used for planning, quantification is common practice only for short-term strategies (e.g. within the framework of legislative periods or three-five-year plans), while long-term planning often takes the form of qualitative visions. Even if some long-term goals are quantified, adequate medium to long-term planning instruments are necessary to secure that short-term planning is compatible with reaching long-term goals.

A broad variety of software tools have been developed over the past two decades to support policy design, analysis and evaluation in the public sector. The most broadly applied categories of such tools include Computable General Equilibrium (CGE) models (Robinson et al., 1999); Macro-Econometric (ME) models (Fair, 1993); and Disaggregated Consistency (DC) models (Easterly, 1989). Most of such tools are fundamentally focused on only one dimension of public policy (e.g. the economic one), and thus do not foster integrated planning. As Allen et al. (2016) recently found, out of the 80 scenario modeling tools they reviewed, only 10 per cent of these met both of the screening criteria “integrated” and “policy relevant”.

In parallel, a few system dynamics (SD) software tools for integrated policy analysis have been developed, among which the Threshold-21 (T21) (Pedercini and Barney, 2010) model
developed by the Millennium Institute is a broadly applied example (Millennium Institute, 2018). The T21 model is a System Dynamics-based model at the national level, and it extends the use of a systemic perspective on performance management in the public sector (Boland and Fowler, 2000) to the assessment of broad cross-sector policy impact. Other prominent examples of SD models for policy analysis include the World3 model (Forrester, 1971), the basis for the Limits to Growth report (Meadows et al., 1972; Meadows et al., 2004); or more recently the C-Roads model, used in global climate negotiations to gain insights into the effects of proposed pledges and policies (Sterman et al., 2012). Models supporting sustainable development planning at the level of large cities are also being developed (Stephens et al., 2016).

Differently from the examples indicated above, T21 is designed to provide concrete information for decision support at the central national level, e.g. on financial allocation. To achieve this end, it makes extensive use of available data, especially for validation purposes. The model thus combines a structural modeling approach (by representing structural relationships that are decisive for development) that allows for structural insights with extensive use of econometric techniques. It is important to note though, that this does not mean that the model is “driven” by data, as change in the key performance indicators in the model are driven by endogenous feedback mechanisms (its structure). While scenarios replicate historic developments, their future trajectories are not limited to what has been observed in the past but can exhibit substantially different modes of behavior – as different structural components become dominant.

The T21 model closes the gap between quantified short-term planning and qualitative long-term visions. Simulation-based long-term policy impact analysis allows for assessing the extent to which short-term planning is properly aligned with the long-term goals. Moreover, as T21 integrates key development mechanisms in different sectors into a coherent framework the model allows its users to see the birds-eye view that uncovers the causal connections across ministry borders.

Through the example of Swaziland, this paper highlights the usefulness of integrated simulation for policy design, analysis, monitoring and evaluation in a highly dynamic development context. Section 2 provides an overview of the key issues and planning system in Swaziland; Section 3 describes the key features of the model; Section 4 presents the results from selected planning exercises; and Section 5 provides a summary of our conclusions.

2. Swaziland: issues and planning system
Swaziland, a land-locked country located between South Africa and Mozambique, has experienced rapid economic growth until the early 1990s, when it entered a period of slow and decreasing growth. Over the past few years, GDP growth has been oscillating between 1 and 2 per cent, and per capita GDP is stabilizing at about $5,350 (PPP, 2005 international). Such major slow-down in growth is because of several, intertwined factors of socioeconomic nature.

On the economic front, Swaziland has been historically tightly connected with South Africa, an important source of foreign direct investment and government revenue (through the South African Customs Union – SACU). However, over the past couple of decades foreign direct investment has been decreasing because of a combination of improving environment in South Africa and worsening environment in Swaziland, also because of a slow pace of economic reforms and a lack of efficiency in the public sector. In addition, SACU revenue has recently dropped as a result of the global financial crisis, further limiting the ability of the government to embrace major reforms.
Despite such difficulties, Swaziland qualifies as a lower-middle-income country according to the World Bank’s classification, with higher per capita income than most sub-Saharan countries. However, such relatively high-income level hides more dramatic socioeconomic developments. Since the mid-1990s, unemployment has been rising (over 28 per cent in 2007) (CBS, Central Bank of Swaziland, 2010), and life expectancy has been dropping from 60 in 1997 to 43 in 2007 [Central Statistical Office (CSO), 1997/2007], as a result of a dramatic HIV-AIDS epidemic. Poverty rates remain high, estimated at 63 per cent in 2010. As a result of the combination of these factors, Swaziland is one of the few countries globally where the Human Development Index has been decreasing over the past 15 years from 0.523 in 1995 to 0.498 in 2010 (United Nations Development Program UNDP, 2010).

Over the past 15 years, Swaziland has been preparing and implementing a variety of planning documents, reflecting development strategies addressing those critical issues. Their planning system includes long-, mid- and short-term planning instruments, hierarchically coordinated so that the shorter-term instruments are based on the outcomes of the longer-term planning exercises (Figure 1). As it is often the case (Marcus et al., 2006), coordination between long-term and short-term policy instruments, as well as between global objectives and sectoral strategies, was limited.

T21-Swaziland was especially conceived to support such process at two levels:

![Figure 1. Overview of the planning process in Swaziland](image)

**Source:** Author’s visual interpretation of information from Ministry of Economic Planning and Development (MEPD). The longest-term planning instrument is the country’s Vision 2022, which includes the long-term goals for the Swaziland’s development. Based on such Vision and other internationally agreed development goals a number of planning instruments are prepared, such as the Poverty Reduction Strategy and Action Programme (PRSAP), National Development Plan (NDP) and the Millennium Development Goals (MDG) report. Plans and strategies developed are then framed in terms of public expenditure through the so-called Medium-Term Expenditure Framework (MTEF), which is then used for the definition of the yearly budgets.
(1) develop integrated, quantitative scenarios to support the otherwise qualitative long-term planning instruments; and

(2) based on such quantitative scenarios, align policies and performance objectives defined in the shorter-term documents with the long-term development goals.

The critical mix of issues of heterogeneous nature that the Government of Swaziland has been trying to address to spur the country’s development cannot be satisfactorily analyzed only by way of purely economic models. A multi-disciplinary approach was required to correctly represent the rapidly changing social and economic factors and analyze their inter-linkages.

3. The threshold-21 Swaziland model

The T21 Swaziland model has been implemented by way of the SD method, well suited to address the high level of dynamic complexity and the multidisciplinary nature of the issues being analyzed. Over the past 20 years, SD has been proven to be effective for the analysis of a variety of development issues (Parayno and Saeed, 1993; Saeed, 1987), including national policy analysis (Qureshi, 2008). The SD method was conceived at the Massachusetts Institute of Technology (MIT) in the late 1950s and widely applied to date in both the private and public sectors (Forrester, 1961). The method uses a graphical stock and flow representation of systems of differential equations, which are then solved via simulation software, such as Vensim (www.vensim.com) or Stella (www.iseesystems.com). SD offers a variety of tools to integrate knowledge from different disciplines into a single modeling language. Key elements of dynamic complexity that characterize the development process – feedback loops, delays and non-linearity – can also be adequately represented. That graphical structure allows for a degree of transparency even to non-modelers and non-mathematicians that cannot be achieved through models that exist in equation form only. This is especially important as it opens up the possibility for participatory approaches such as co-creation and validation by subject-matter experts and societal stakeholders. The above-described characteristics make SD ideally suited to analyze development issues from an integrated and long-term perspective.

To develop our model, we used as starting framework the Threshold-21 (T21) model originally developed by the Millennium Institute in the mid-1990s (Bogdonoff et al., 1997). Profoundly revised at the outset of the MDG era (Barney, 2002), the model has been elaborated and improved ever since through its application as an integrated scenario-analysis tool designed to support national development planning in various countries (Pedercini, 2011). To achieve a high level of confidence from the final operators (i.e. government’s technical staff) in the use of the model, we applied a collaborative modeling approach (Andersen et al., 1997). Under such approach, the local technical staff was actively involved, from the beginning, in the definition of the model’s scope and structure, and their input was facilitated throughout the modeling process (Ford and Sterman, 1998). As a result, the T-21 local development team eventually gained in-depth understanding of the model, its database and assumptions, which brought about a good level of confidence of the government in the applicability of T21 to the analysis of the most pressing development issues.

The resulting T21-Swaziland is a large-size model (1,742 stocks), consisting of 45 dynamically interacting subsectors, organized in 18 sectors and three spheres: society, economy and environment. Figure 2 provides a graphical overview of the structure of the model, including the three spheres and the 18 sectors.
In the economy sphere, production is the key sector. Here resources of various natures—economic, social and environmental—converge to generate economic production. We adopt a Cobb–Douglas production function (Cobb and Douglas, 1928) with an endogenous treatment of total factor productivity (TFP). Endogenous is to mean here that the TFP is not a fixed parameter nor is it fed into the model as time series data, but it is continuously calculated during the simulation based on other model variables that represent key resources for the country’s development. Such are e.g.: physical capital, human capital (also including education and health factors) and infrastructure (Sacerdoti et al., 1998, Calderón and Servén, 2004). In addition to these, we also consider the effect of affordable energy, environmental resources, such as agriculture land and mineral reserves in the analysis. The production sector includes 10 subsectors, which provide a sufficiently detailed representation of the local economy for long-term, integrated analysis. The resources generated through economic production are allocated between consumption and investment. Investment in physical capital mostly takes place in the private sector, enhanced by foreign direct investment and remittances from abroad. Investment in human capital, via better education and health, fundamentally takes place as public spending in the education and health sectors. Key public infrastructure (such as transportation infrastructure) also develops as a result of public investment.

In the Society sphere, the population sector represents the key mechanisms underlying demographic development. Population is subdivided into 81 age-cohorts and two genders, and it allows for the monitoring of specific age-related or gender related indicators (e.g. infant mortality). Fertility is determined based on income and education (Birdsall, 1988) and mortality based on income and access to health care (Rodgers, 1979,
HIV/AIDS – A major cause of mortality, especially before medication became available to the population of Swaziland – is represented in a subsector that was custom-created for the country, which represents the dynamics of infection and progression of the disease in the individual and diffusion through the population. The labor sector accounts for labor supply/demand balances, distinguishing between female and male labor. The health and education sectors determine, respectively, the level of access to basic health care and the adult literacy rate, based on the level of public service offered. The poverty sector determines the level of monetary poverty using the empirically observed density distribution function, and the infrastructure sector represents specifically roads and irrigation infrastructure.

In the environment sphere, land, water, minerals and other natural resources are used to sustain production and to cover basic needs and are regenerated based on their natural cycles. Some of these resources, such as coal, are not renewable; others such as water are renewable but available only in limited quantity and locations; and others such as land are fixed but can be shifted to a limited extent among different uses. Energy is generated using both internal resources (e.g. hydropower and coal) and external resources (imported fossil fuels) (US Energy Information Administration EIA, 2010). Long-term sustainability is assessed using an adaptation of the ecological footprint (Monfreda et al., 2004), which is determined in a simplified manner based on the emissions from energy production and the other standard components of the footprint taken as constant on a per capita basis.

The model has been undergoing a thorough validation process involving structural as well as behavioral validation tests (Barlas, 1996). Structural validation involved direct verification of structural assumption as well as of parameters, carried out in collaboration with the local T21 development team. Behavioral validation involved especially the comparison of the model’s behavior with historical data for the period 1980-2010: the model was initialized in 1980, and its ability to reproduce development trends for key indicators was assessed.

The T21-Swaziland model thus constructed allows for the simulation of a variety of public policies and for the analysis of their direct impact on the target sector, as well as of their indirect system-wide impacts. The model is especially designed for long-term (2035) policy analysis, but it provides quasi-continuous output along the whole simulation period, facilitating the alignment of short-term policy instruments with the country’s long-term goals. The examples presented in Section 4 highlight how the model is being used to enhance the government’s planning activities.

4. Results
This section includes a summary description of the main applications of the model by the Government of Swaziland. The objective is to provide an appreciation of how the tool and the process of its construction and application for ex ante policy assessments and policy design led to improved decisions for the country. The cases described below show how the overall institutionalization effort increased the government’s efficacy in designing, analyzing, monitoring and evaluating public policies.

Broadly, the multiple policy exercises carried out through the T21-Swaziland model led to the identification of a series of interconnected development mechanisms that are especially important drivers of the major issues the country is facing; and that present key leverage points for intervention. Those mechanisms are represented in a simplified manner in the Causal Loop Diagram (CLD) in Figure 3. Differently from the more detailed, quantitative representations included in simulation models, CLDs provides a qualitative
description of the fundamental structural components of the system being analyzed (Richardson, 1986). The brown structure in Figure 3 represents the reinforcing feedback loop of capital reinvestment. While economic growth is certainly a key ingredient of development, the Figure shows other important indicators of development such as health, education or infrastructure that importantly affect productivity and thus economic growth (GDP). As investment in these key resources is dependent on economic growth (the availability of financial resources depends on it), each of these indicators is connected with GDP in a feedback loop, highlighted in color in Figure 3. These feedback loops together with the capital growth loop mutually reinforce each other because they are all connected through GDP. If, for example, an intervention leads to a higher education level, all other feedback loops will operate more efficiently and the resulting elevated GDP will again allow higher investments in education (and the other fields). Moreover, the model contains numerous cross-sectoral influences some of which are indicated in Figure 3: better road infrastructure with shorter transport times will allow more children to go to school and both higher education level and higher incomes contribute to the health of the population. Finally, the green feedback loop represents in an aggregate manner the broad constraints on economic growth imposed by the limited natural resources available, critical in Swaziland for sectors such as livestock, crops and mining. Although highly simplified, the resulting feedback structure represents a valuable tool to understand and interpret the simulation results described in the paragraphs below.

4.1 Millennium development goals report
The Kingdom of Swaziland is a signatory of the United Nations Millennium Declaration and in September 2010 presented its 2010 MDG report (Government of the Kingdom of

Notes: Capital growth loop in brown, cross-sectoral connections in red dashes. The polarities indicate the type of causal link: +/-: same/opposite direction of change in the affected variable as compared to the variable initiating the change (for details on CLDs notation see Sterman, 2000)
Swaziland GOKS, 2010, summarizing results and remaining challenges for the achievement of the MDGs. The 2010 MDG report followed the 2003 and 2007 reports, and it is one of the country’s fundamental planning instruments. T21-Swaziland is especially used as a tool for MDG analysis, as the model provides projections for nearly all of the MDGs (with the exception of MDG 8, which focuses on international cooperation to achieve the other MDGs). Hence, the model provides a comprehensive picture of the country’s progress toward the MDGs in the various areas, enhancing coherency between projections for the different Goals.

For instance, Millennium Development Goal 1 – eradicate extreme poverty and hunger – is among the main challenges that Swaziland is facing. Progress in terms of poverty reduction has been alternating over the past two decades, affected by a number of economic and non-economic factors. Monetary poverty, being calculated based on individuals’ available income, is clearly directly affected by GDP and other sources of income, such as workers’ remittances or government transfers. However, beyond such direct factors, a number of other factors affect poverty rates, also including the level of employment and education, which determine the level of inclusivity of the economy, and hence, there is inequality in the distribution of income. Furthermore, the dramatic HIV/AIDS epidemic that Swaziland is experiencing is also affecting poverty via reduced economic growth through decimating and weakening the labor force. The epidemic also caused many orphans to drop out of school (see Figure 3), decreasing the country’s potential for economic development in the long run. By considering all such factors, T21 allowed for the analysis of projections for MDG1, coherently with the expected developments on the other key socioeconomic issues (Figure 4).

In such complex context, where a multitude of factors affect the country’s effort toward poverty reduction, T21 provided support in understanding how the different key factors played together leading to the current situation. As can be seen in Figure 4, the analysis indicated that, despite a period of actual increase in poverty figures, poverty recently embarked again on a decreasing path. This is an example of so-called “worse-before-better” development, where simulation models can help policy makers to look beyond the most immediate difficulties to implement effective long-term strategies. Nevertheless, MDG poverty goals are projected to be reached only toward 2025/2035, about a decade later than the MDG-target-year 2015. Further effort is thus required to

accelerate poverty reduction. The following subsections provide examples of how T21 was used to estimate the impact of different strategies and policies on economic growth and poverty.

4.2 Economic recovery strategy

Coming from more than a decade of reduced economic growth, one of the main challenges that the Government of Swaziland is facing is to identify strategies for strong, inclusive and sustainable growth. This is the main goal of the Economic Recovery Strategy (ERS) that was finalized by the Ministry of Economic Planning and Development in 2011 (Ministry of Economic Planning and Development of the Government of the Kingdom of Swaziland MEPD, 2011). The development of the ERS was based on an open and participatory process to solicit inputs from a wide variety of stakeholders and led to the identification of key areas for intervention: foreign direct investment, domestic investment, trade, tourism, the fiscal sector, agriculture, financial services, information communications and technology, human capital development and infrastructure.

The Threshold21-Swaziland model was then used for simulation of alternative policies in each of these areas, to understand their impact first in isolation and then in combination, including potential synergies and cross-sector influences. The analysis led to the identification of an integrated policy package, bringing about substantial growth acceleration in the short run, to be followed by sustained growth in the medium and long term (Figure 5). The shorter-term growth is driven primarily by the growth in investment and physical infrastructure, that have relatively short implementation delays and can deliver an important contribution to economic growth within 2-3 years from the moment the intervention takes place (brown and orange feedback loops in Figure 3). The longer-

![Graph showing GDP Growth rate under different scenarios](image)

**Source:** T21-Swaziland, MEPD
term growth, on the contrary, is a consequence of the increased investment in education and health, which lead over the years to a more productive labor force (blue and purple feedback loops in Figure 3).

In addition to important results in terms of economic growth the ERS was also projected to have major impacts in terms of employment, with the formal employment rising steadily over the period of simulation, more than doubling over the coming 25 years (Figure 6). This also implied a substantial acceleration in poverty reduction and other improvements for key socioeconomic indicators.

Results of this strategic exercise indicated a clear and well outlined way out of the extended period of reduced economic growth and identified positive synergies among the proposed policies. Synergy is to mean here that the implementation of the ERS in its entirety would lead to more than proportional results with respect to what one should expect from the sum of the results of implementing individual policies in isolation.

In addition, the ERS identified the need for the establishment of a clear institutional and monitoring and evaluation framework. Quantitative simulation results such as those produced by the Threshold21-Swaziland model are especially useful to support monitoring and evaluation, as they provide clear milestones against which to compare the actual country’s performance.

4.3 Budget analysis
To put the nation’s public finance on a sustainable path, in 2012 the Government of Swaziland was studying a variety of measures to reduce its deficit. Among others, such measures included a reduction in the wage bill; the freezing of public consumption at the 2011/2012 levels; a moderate decline in the level of subsidies and transfers; and enhanced tax collection measures. Such combination of measures had been proposed as the “fiscal

![Figure 6. Formal employment under different scenarios](source: T21-Swaziland, MEPD)
adjustment” package and it was expected to bring about important improvement in public finances in the short term, although its medium to long-term implications had remained uncertain.

By using the T21-Swaziland model, the local T21-team performed an analysis of the impact of the proposed fiscal adjustment on future development of the Swaziland economy over the medium to long term (Ministry of Economic Planning and Development of the Government of the Kingdom of Swaziland MEPD, 2012). The results of the Budget Analysis (Table I) indicate that under the fiscal adjustment scenario, while achieving a quick reduction in deficit (“Surplus or Deficit to GDP” in Table I), also leads to a slow-down in economic growth (“Real GDP growth rate” in Table I). This is because of the fact that the strong initial adjustment – by reducing spending and increasing taxation – would have a relevant and permanent dampening effect on economic activity. While investment in physical capital and infrastructure can be restarted relatively quickly after such adjustment period (brown and orange feedback loops in Figure 3), our analysis shows how the slow-down in building of human capital caused by the budget cuts to education and health would take longer to recover (blue and purple feedback loops in Figure 3). Consequently, although the fiscal adjustment would be successful in restoring the public finances over the short terms, it would create the foundation for a weaker revenue base and therefore larger deficit in the long run.

As a result of the slower economic growth and more limited ability of the government to invest in key areas determined by the fiscal adjustment package, poverty reduction in the country is expected to experience a slow-down under this scenario (Figure 7). The analysis thus highlights the long-term unsustainability of the proposed fiscal adjustment – i.e. its incompatibility with the country’s long-term development goals. The Budget Analysis also provides key recommendations, including accompanying the fiscal adjustment with targeted policies to stimulate economic growth and employment, as well as an enlargement of tax base.

5. Conclusions
In highly dynamic development contexts, assessment and management of public sector’s performance requires the use of tools that allow designing effective integrated policies and strategies, estimating their potential impact and supporting their monitoring and evaluation. Such tools can be especially useful to assess performance considering the

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<tr>
<td>Total revenue and grants (E’ billion)</td>
<td>7.60</td>
<td>5.60</td>
<td>8.20</td>
<td>8.21</td>
<td>9.03</td>
<td>10.71</td>
<td>12.67</td>
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<td>Total expenditure and net lending (E’ billion)</td>
<td>10.89</td>
<td>8.38</td>
<td>8.22</td>
<td>9.26</td>
<td>11.04</td>
<td>13.29</td>
<td>15.93</td>
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<tr>
<td>Surplus or deficit (E’ billion)</td>
<td>-3.30</td>
<td>-2.68</td>
<td>-0.83</td>
<td>-1.04</td>
<td>-2.01</td>
<td>-2.58</td>
<td>-3.26</td>
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<tr>
<td>Total government debt (E’ billion)</td>
<td>6.26</td>
<td>9.16</td>
<td>10.70</td>
<td>11.09</td>
<td>12.54</td>
<td>14.80</td>
<td>17.67</td>
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<tr>
<td>Real GDP growth rate (%)</td>
<td>2.0</td>
<td>1.1</td>
<td>-0.8</td>
<td>-0.6</td>
<td>0.4</td>
<td>1.3</td>
<td>1.7</td>
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<tr>
<td>Proportion of population below poverty line (%)</td>
<td>63</td>
<td>65.5</td>
<td>62.6</td>
<td>64.3</td>
<td>64.7</td>
<td>64</td>
<td>63.2</td>
</tr>
<tr>
<td>Nominal GDP at market prices E’ billion</td>
<td>25.37</td>
<td>26.31</td>
<td>30.6</td>
<td>32.55</td>
<td>35.86</td>
<td>40.5</td>
<td>45.82</td>
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<tr>
<td>Surplus or deficit to GDP (%)</td>
<td>-13.0</td>
<td>-10.2</td>
<td>-2.7</td>
<td>-3.2</td>
<td>-5.6</td>
<td>-6.4</td>
<td>-7.1</td>
</tr>
<tr>
<td>Debt to GDP (%)</td>
<td>24.7</td>
<td>34.8</td>
<td>35.0</td>
<td>34.1</td>
<td>33.0</td>
<td>36.5</td>
<td>38.6</td>
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**Table I.**
Results of the fiscal adjustment scenario

**Note:** E’ = Emalangeni, Swaziland’s currency

**Source:** MEPD budget analysis paper
complex, system-wide ripple effects of potential interventions. The application of the Thresold21 model to Swaziland illustrates how dynamic, integrated models can help enhancing government performance at different levels.

First, by integrating sectors of diverse nature and by producing quasi-continuous output over a long-time horizon, such models can facilitate the integration of different planning instruments, improving efficiency and coherency in the planning process. Second, by being transparent and flexible in their assumptions, models like T21 support open and inclusive planning, where input from multiple stakeholders can be factored into the analysis. Third, dynamic, integrated models facilitate the identification of effective policies through the assessment of their potential impact across sectors, including the discovery of unintended (and sometimes undesirable) impacts. Finally, by indicating clear milestones toward the stated objectives, the results from the analysis provide a quantitative supporting framework for policy monitoring and evaluation.

To profit of such benefits, the model implementation process is designed accordingly to government’s planning needs. In particular, the structure of the local planning process should be carefully considered, and capacity development activities are included to facilitate a full technological transfer.

The recently launched UN Sustainable Development Goals (United Nations General Assembly UN, 2015) promote a comprehensive framework for sustainable development and make a strong call for policy integration. The T21-model such as the one used in Swaziland is considered the most suitable tool for governments for SDG-related planning (Allen et al., 2016). As the number of applications of this type of models is rapidly increasing, further research on the benefits that such tools provide to improve governance toward sustainable development is envisioned.

**Figure 7.**
Proportion of population below the poverty line

**Source:** MEPD Budget Analysis Paper
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