System dynamics and agent-based modelling to represent intangible process assets characterization

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Abstract

Purpose – This paper aims to address the use of modelling and simulation tools to enhance intangible process assets management by simulating and automating their characterization depending on their quality and impact on an organizational business goal.

Design/methodology/approach – The authors conducted a study comparing two simulation-based approaches to characterize intangible assets: system dynamics and agent-based simulation.

Findings – Strategic business studies have not yet considered the use of simulation techniques to characterize the intangible assets at length. The proposed solution introduces significant improvements for strategic data visualization, providing company stakeholders with a practical and helpful prism through which to view an easily adaptable, cheap and meaningful source of information about their company's process assets, and their behaviour based on operation indicators.

Practical implications – This research offers decision-makers in knowledge-intensive organizations alternatives for effective strategic decision-making and for leveraging prospective views based on the specification of the organization's knowledge. To do this, stakeholders will be able to use very promising low-cost simulation-based tools to create practical scenarios and potential situations that generate inputs for debate and decision-making by senior and middle management.

Originality/value – This paper reports an unprecedented comparative study of system dynamics and agent-based simulation to speed-up the characterization of the intangible process assets based on their quality and impact on strategic goals. It stresses the benefits and implications of the use of these techniques for better strategic management.

Keywords Modelling and simulation, System dynamics, Agent-based simulation, Assets management, Characterization of intangible assets, Study of business intangibles

Paper type Research paper

1. Introduction

Knowledge-intensive organizations are companies that are conscious of the importance of their knowledge for survival in the changing environment of the twenty-first century. They all have one thing in common: they need to pursue and achieve their business goals with the aim of surviving, adapting and, at best, evolving with the environmental requirements. To do this, they need to bear in mind one of their most important resources: their know-how. Know-how has been studied at length by academic branches of knowledge concerned with intellectual capital, strategic management or process improvement. However, research from the viewpoint of its usefulness in the corporate world is scant (Demartini and Paoloni, 2013). The focus of this paper is on the elements of organizational knowledge that affect and define good or poor organizational operation, i.e. intangible assets.

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Strategic planning and prospective value-based studies usually focus on economic and performance indicators that do not actually consider knowledge in any of its forms. This, however, is not admissible for strategic studies in knowledge-intensive organizations, i.e. studies aimed at comprehending and defining the future of organizations based on the actual and available value of knowledge, practices, resources and contextual constraints. This is why recent works continue to systemically focus on the added value of knowledge for management (De Toni *et al.*, 2017).

In their quest to rise above the purely economic perspective, knowledge-intensive organizations should, in any case, try to consider their tacit and intrinsic value. Some knowledge is held by people, some is contained in documents, some is included in practices and some is present in organizational culture (Edvinsson, 1997). All this knowledge, which represents the company's know-how and differential, is a fundamental aspect influencing company's growth and competitive advantage (Grant, 1996; Spender, 1996). However, traditional formal valuation models in industry do not explicitly take into account the value of knowledge (Demartini and Paoloni, 2013).

Knowledge, present in any organization in the form of intangible assets, must be measured to ascertain how healthy a company is. Knowledge assets provide guidelines and criteria for tailoring the organization's processes to the specific needs of companies and projects (P.M.I., 2013a, 2013b) Besides, this measurement must be made considering the alignment of intangible assets and strategic or business goals, the relationships between strategic goals (SGs) and intangible assets, how each affects the other and the unequally distributed importance of assets with respect to a goal (Sanchez-Segura *et al.*, 2017a; Sanchez-Segura *et al.*, 2017b). This defines a complex system that is not easy to understand from the angle of traditional paradigms. Modern organizations are creating niches and opportunities for technologies and approaches that better address the assessment and valuation of their intangible assets, i.e. their know-how. In this respect, systems thinking and its different variants are of particular interest and significance because these take into account the system-inherent complexity of intangible assets and provide a holistic perspective. Systems thinking is, therefore, a broad field able to deal with complex problems and systems related to knowledge assessment and also provides the contextual background for systemic solutions such as the proposals presented in this paper. Systems thinking helps stakeholders to view problems and systems as *holons* (unique systemic perspectives of a system) composed of elements (items of knowledge in this case) and relationships. As a whole, this interactivity reveals much more information than the analytical study of their parts. Both hard and soft systemic approaches are potentially applicable for this purpose (Gao *et al.*, 2002).

A company's success will depend on strategic management taking into account its intangible assets (Pike *et al.*, 2005; Greco *et al.*, 2013; González and Dopico, 2017). However, this issue is usually underestimated. Strategic goals are the essence of organizations and define the target towards which all activities and policies should be aimed. Strategies and actions driving companies towards the achievement of even apparently clear organizational business goals are no longer sufficient. In fact, their complexity (as a system), which is mostly overlooked, has obscured the understanding of how an organization can function effectively. Intangible assets can be used as levers to achieve business goals if they are considered under the systems thinking paradigm. Specifically, simulation modelling appears to be a good approach for, first, representing and, second, understanding the complexity of an organization's intangible assets system, represented primarily by its knowledge assets.

The dominant trend is to conduct strategic studies based on economic and general information. This approach fails to take into account the organization's intangible assets. Although intangible assets have a direct impact on the functioning of the organization, they are not usually considered directly. In an attempt to improve upon this, this paper is a contribution to finding a practical solution, driven by simulation tools, for measuring and characterizing intangible assets based on their quality and impact on the organization's strategic objectives. The main aim of this paper is to illustrate how useful modelling and simulation tools, specifically NetLogo and Vensim, are for characterizing the intangible process assets (PAs) of the organizations according to the SIPAC methodology (Sanchez-Segura *et al.*, 2017b).

2. Role of intangible assets in organizations: current perspectives

PA valuation or assessment models address four different but connected perspectives (Sanchez-Segura *et al.*, 2016a, 2016b):

1. the software process improvement perspective;
2. the strategic management perspective;
3. the knowledge management perspective; and
4. the intellectual capital perspective.

The cornerstone of the *software process improvement perspective* is that organizational processes are very important and organizational behaviour is directly dependent on the organization's process implementation.

Software process use and improvement have been recognized by industry and academia as a critical factor for the success of software development organizations (Allison and Merali, 2007; Amescua *et al.*, 2010; Software Engineering Institute, 2010; Harter *et al.*, 2012; Lavallee and Robillard, 2012; Kuhrmann *et al.*, 2015). Some authors have declared that the success factors for process deployment and improvement include commitment, strategy and business goals alignment, training, communication, resources used, people personal skills and improvement management (Rossi and Hirama, 2015; Khan and Keung, 2016). Some authors go so far as to explicitly recognize PAs as being the key elements for deploying and improving processes in software development organizations (Amescua *et al.*, 2010; Software Engineering Institute, 2010; P.M.I., 2013a; Sanchez-Segura *et al.*, 2016b; Saunders and Brynjolfsson, 2016).

Specific works relating to software PAs from a process improvement perspective are Plösch *et al.* (2011), Sun and Liu (2010) and García *et al.* (2010). These works propose different ways in which to address the same problem, namely, how to define a process improvement strategy whose objectives are aligned with the strategic objectives of the organization. One (Sun and Liu, 2010) is specific to capability maturity model integration (CMMI)-based process improvement, and the other two can be used with both CMMI and any other process improvement model implemented by the organization. Although these proposals are useful for defining process improvement strategies that are aligned with the achievement of organizational business objectives, they do not consider PAs as key process deployment and improvement elements. Therefore, their scope does not embrace an analysis of whether organizations have the right assets to deploy and improve their processes.

From the *perspective of strategic management*, if software PAs are internal elements used to describe, deploy and improve the processes to achieve business objectives, these assets must be analysed in the light of their contribution to business objectives. This would enable decision-making about the evolution of such PAs to positively affect their impact on the organization, improving its contribution to the achievement of business objectives. Strategic management entails a number of analyses, decisions and actions that an organization carries out to create and maintain a competitive advantage. The strategic management processes are strategy analysis, strategy formulation and strategy implementation (Dess *et al.*, 2004).

Strategy analysis must define the business objectives and the internal objectives of the areas to direct the efforts of the whole organization towards a common goal. One of the key attributes of strategic management is that it should be aimed at the goals of the whole organization, that is, the effort must be directed towards what is best for the whole organization and not only for a particular area (Thompson, 1993).

Strategy formulation defines how the organization plans to surpass the competition and how it will generate and sustain a competitive advantage over time (Dess *et al.*, 2004). Finally, a perfectly analysed and formulated strategy is of little use if it is not implemented correctly. One of the key elements in implementing the strategy is to deploy control mechanisms to determine whether the strategy is being carried out as expected and whether business objectives are being met (Dess *et al.*, 2004).

From the *perspective of knowledge management*, knowledge has been classified in different ways. A fairly generalized classification explains that there are two dimensions of knowledge in organizations: explicit and tacit (Nonaka, 1994).

Knowledge management is the set of activities to create, store, retrieve, transfer and apply organizational knowledge. This contribution to improving the performance of organizations is a vital factor for their growth, a major source of sustainable competitive advantage and a key strategic asset that influences value creation (Zack, 1999; Alavi and Leidner, 2001). Knowledge management activities are:

- creation of knowledge;
- storage and retrieving of knowledge;
- transference of knowledge; and
- deployment of knowledge.

Knowledge management is, therefore, a mechanism for improving the productivity of software development organizations, improving development processes, reducing development time and costs, increasing product quality and making better decisions (Aurum *et al.*, 2008; Bjørnson *et al.*, 2009; Basili *et al.*, 2010).

To manage their knowledge, organizations must design knowledge management strategies (Coakes *et al.*, 2009). These strategies must be associated with the business objectives of the organization, seeking to determine how knowledge assets add value to the business.

From the *perspective of intellectual capital*, it is important to recognize the importance of intellectual capital in organizations of different sizes belonging to different industrial sectors, including the software industry. This issue has been widely studied and tested. Intellectual capital has been positively related to improved productivity, improved profitability, innovation capacity, growth capacity and the market value of organizations (Ferreira *et al.*, 2012; Mosavi *et al.*, 2012; Ngugi, 2013). In addition, intellectual capital has also been identified as being important for the growth of countries through its relationship with the gross domestic product (GDP) (Dutz *et al.*, 2012).

Intellectual capital consists of all the intangible assets that contribute to the development of products and services. Intellectual capital classifies intangible assets into three types of capital: human capital, relational capital and structural capital (Petty and Guthrie, 2000;

Marr, 2008). The intellectual capital discipline studies the identification, measurement and valuation of the intangible assets that make up an organization's intellectual capital, but the impact of intangible assets measurement on business goals is forgotten.

3. Approach for accounting for intangible assets in organizations from a systemic perspective

We have developed an approach that encompasses all the perspectives outlined in Section 2. This approach sets out to be systemic and adaptable to specific cases. This research could be said to take a different systemic approach to organizations. It is aligned with research by Bakken *et al.* (1992), Sterman (1994) and Lane (1995), who designed management flight simulators for strategically comprehending and visualizing company behaviour. Indeed, it is different from and more evolved than balanced scorecards and other traditional techniques to the extent that it focuses on the effect of the intangible PAs on organizational performance. It also looks at how simulation tools have been powerful promoters of information emergence, which proved to be one of the main levers for competitive and viable companies in the past century. This approach (Sanchez-Segura *et al.*, 2016a; Sanchez-Segura *et al.*, 2017b) considers the intangible PAs to be part of the so-called intellectual capital of an organization (Roos *et al.*, 1998; Axtle, 2006). Intellectual capital is critical in several respects. For instance, it has an impact on a country's GDP (Ståhle and Ståhle, 2012) and propagates empowerment if applied to small- and medium-sized companies.

This approach recognizes that one of the main factors that have influenced misunderstandings with respect to strategic management in organizations is the contention that the intangible PAs (knowledge, organizational models, policies, practices, repositories, etc.) have a direct effect on an organization's performance, economics and functioning (Stewart and Ruckdeschel, 1998; Marr, 2008). In addition to tangible assets, intangible assets contribute to organizational behaviour indicator values and must be taken into account if a real and effective strategy is to be implemented. An organization with better intangible PAs has better prospects of long-term success (Andrews and Serres, 2012; Greco *et al.*, 2013; Khan, 2014).

In the information technology industry, intangible assets have also been recognized as strategic components (Saunders and Brynjolfsson, 2016). Although valuable, the strategies accounted for by the usual studies are improvable because most of these strategies consider only an organization's tangible side. Innovative studies also considering intangible assets have produced better results.

Sanchez-Segura *et al.* (2017b) reported the SIPAC methodology for characterizing intangible assets. Accordingly:

> [. . .] the main advantage of simulating process assets is that it is not feasible to manipulate real process assets for experimental purposes, since they are key enablers for business performance and represent high-cost risks that not every company can afford.

By contrast, simulation models are practical tools for experimenting with and estimating the performance of PAs, as well as their effect on the strategic objectives within routine and out-of-the ordinary scenarios such as business collapse.

For this approach, presented later based on two simulation models, each intangible PA has an indicator of quality (Q) and impact (I) with respect to an SG defined for the organization. According to Sanchez-Segura *et al.* (2017b), there must be at least one impact and one quality indicator because the characterization is based on two dimensions of equal importance for strategic studies. Up to five indicators are used in the simulation models presented here because PAs are seldom likely to have more than five indicators. However, this is not out of the question, and the original methodology is open to the use of more than five indicators. Being a number between 0 and 1, all relational coefficients add up to a total of 1 (weighting the importance of each PA for the achievement of SGs). Dynamic relations between PAs and strategic objectives take into account these coefficients and compute a performance rating for SGs and an indicator of the wellness of each intangible asset.

PAs are characterized as a function of their indicators and their individual computed wellness, according to which each asset can be labelled as a "warning", "replaceable", "evolving" or "stable" PA, providing an input for the decision-making process regarding the strategic valuation of the organization.

Figure 1 is an overview of the epistemological model underlying our research. All knowledge assets in this model are elements representing the know-how of the company. This is the target on which strategic studies in this proposal focus. The observer, which may be a company's Chief Information Officer (CIO), a consultant or any other senior management stakeholder, must observe the "information", i.e. knowledge, set and identify, classify and characterize the PAs. The methodology for identifying and representing the PAs has already been reported (Sanchez-Segura *et al.*, 2016b). However, this research goes a step further in which it reports two tools based on systems thinking designed to facilitate the characterization of these PAs based on SIPAC methodology indicators and measurements (Sanchez-Segura *et al.*, 2017b). These tools should maximize the advantage to be gained from this characterization by rendering dynamic and easily manipulable what were previously static graphs and reports, by discussing scenarios (simulated), the effect of changes on the system and the achievement of SGs.

Given the indicators for each PA (up to five for each), related to either the impact on the SG or the asset quality, general computed impact and quality indicators are given by the average function of all indicators of the same type for an asset. Specific equation details can be found in the research conducted by Sanchez-Segura *et al.* (2017a). Once the impact and quality for each PA have been computed, PAs are characterized according to their interrelationship according to specified rules.

As defined by Sanchez-Segura *et al.* (2017a), impact can be significant or insignificant, and quality can be satisfactory or unsatisfactory. Following the original proposal, the four possible combinations of impact and quality provide four possible

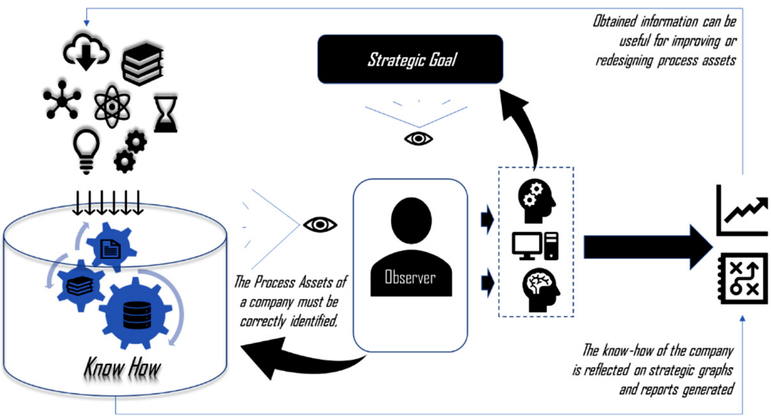

Figure 1.
Process assets conceptualization

characterization states: warning (for insignificant impact and unsatisfactory quality), replaceable (for insignificant impact and satisfactory quality), evolving (for significant impact and unsatisfactory quality) and stable (for significant impact and satisfactory quality). Figure 2 illustrates and identifies the characterization for each of the models presented in this paper.

Given a quality threshold (Qt) and an impact threshold (It), the characterization (CH), as a function of impact (I) and quality (Q) measurements, is the result of evaluating the following rules:

- if (I < = It) and (Q < = Qt), then CH = "warning";
- if (I > It) and (Q < = Qt), then CH = "evolving";
- if (I < = It) and (Q > Qt), then CH = "replaceable"; and
- if (I > It) and (Q > Qt), then CH = "stable".

The impact and quality indicator thresholds and the values are the results of audits and data collection. They are transformed into values according to the equations and rules presented in the study conducted by Sanchez-Segura *et al.* (2017a). The impact and quality indicators used to calculate the overall impact and quality evaluation of each PA are also calculated according to averages and normalizations described and discussed in the study conducted by Sanchez-Segura *et al.* (2017b).

Two simulation models are presented below. One is based on the agent-based paradigm and the other on the system dynamics paradigm. Both models have been specifically calibrated and built with partial data for the same case study: a software development company.

For both of these simulation models, the intangible PAs that have been considered are:

- *Process Asset 1*: kick-off meeting document;
- *Process Asset 2*: proprietary Web project management system;
- *Process Asset 3*: customer communication skills at a technical and managerial level; and
- *Process Asset 4*: course development process experience.

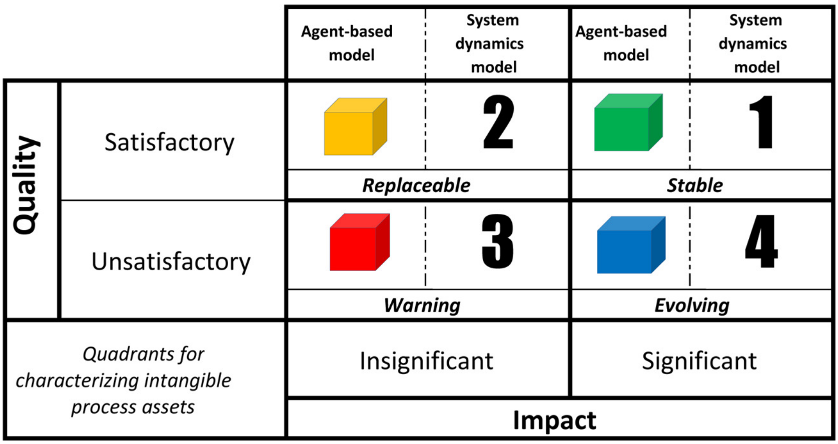

Figure 2. Characterization in each of the simulation models

Because each PA needs to be measured by specific impact and quality indicators, it is necessary to list the PAs concerned and their indicator types (impact or quality).

The Process Asset 1, "kick-off meeting document", has been assessed using the following five indicators:

(1) requirements elicitation efficiency (*Quality*);
(2) requirements elicitation efficacy (*Quality*);
(3) customer learning of the kick-off process (*Impact*);
(4) customer conformance with Gantt diagram (*Impact*); and
(5) approved proposals (*Impact*).

The Process Asset 2, "proprietary Web project management system", has been assessed using the following three indicators:

(1) usability (*Quality*);
(2) proposal validation time (*Quality*); and
(3) number of iterations per project (*Impact*).

The Process Asset 3, "customer communication skills at a technical and managerial level", has been assessed using the following three indicators:

(1) customer knowledge process (*Quality*);
(2) customers perform activities within the process (*Impact*); and
(3) clients brought forward activities from later on in the process (*Impact*).

The Process Asset 4, "course development process experience", has been assessed using the following two indicators:

(1) customers have faith in project manager instructions (*Quality*); and
(2) number of iterations per project (*Impact*).

Evidence about how indicators are measured and correlated can be found in the study conducted by Sanchez-Segura *et al.* (2017a).

Section 3.1 below presents the agent-based model (available for use and manipulation at: http://spaengineering.sel.inf.uc3m.es/index/SIPAC.html) and Section 3.2 presents the system dynamics model.

3.1 Agent-based model

We present a model for characterizing the intangible PAs based on an agent-based approach developed by Sanchez-Segura *et al.* (2017a). Using an evolution of this agent-based simulation model (Sanchez-Segura *et al.*, 2016a), the modeller (and any other stakeholder) can dynamically modify coefficients and weights to visualize in real-time how variations in the model parameters affect the wellness of the intangible assets and performance of the SGs (hence, intangible PA quality and impact indicators). Colours are used to represent the characterization of each intangible PA depending on its quality and impact indicators, as shown in Figure 2.

The characterization process is reported in the study conducted by Sanchez-Segura *et al.* (2017a) as follows:

- *Configuration of initial parameters*. This step sets all the sliders corresponding to the indicator values for the company.
- *Creation of the world*. This step creates the PAs in the form of agents that exist in the world. These agents have not yet been valuated or assessed.
- *Assessment of PAs*. This step assesses the PAs according to their indicator values.

Figure 3 illustrates the characterization according to this agent-based approach. In this case, PA1 has been characterized as "evolving" (blue), PA2 and PA4 have been characterized as "stable" and PA3 has been characterized as "warning".

This agent-based model gives stakeholders visual information that is very useful for decision-making and discussions regarding the status of the intangible PAs. The straightforward quadrant view implemented gives any viewer an idea of the wellness of the intangible asset in two ways: the colour and the quadrant. Accordingly, anyone acquainted with this tool would know right away that the red assets located in the lower-left quadrant need immediate attention because they are not leveraging the SG; on the other hand, the green assets located in the upper-right quadrant are in very good form and should be used to achieve the SGs.

3.2 System dynamics model

A system dynamics model has been developed to assess the intangible PAs. Figure 4 shows the created simulation model. There are input variables (for the PA indicators), computed variables, flows and a level (indicating whether or not an SG should be achieved).

The model can be seen as an interactive representation with sliders and graphs represented in the model itself. Using the Vensim SyntheSim functionality, it is possible to synthesize the model structure and the simulation behaviour, displaying small graphs for all dynamic variables and sliders set-up for all the constants. As a slider is moved, the model will be simulated and the graphs plotted automatically. Sliders for PA1 parameters are shown in Figure 5.

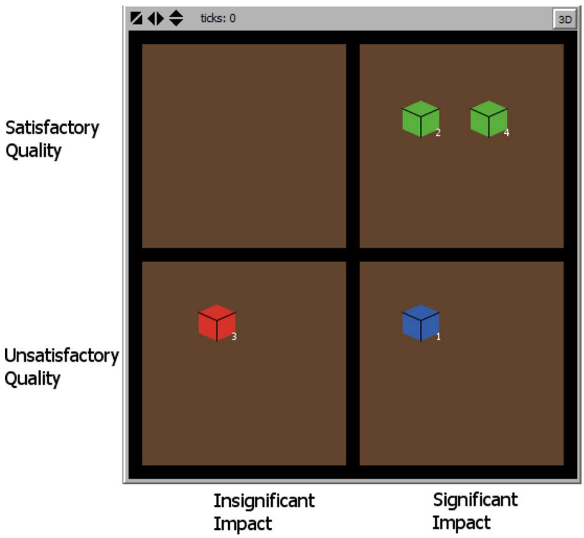

Figure 3. Agent-based characterization of intangible process assets

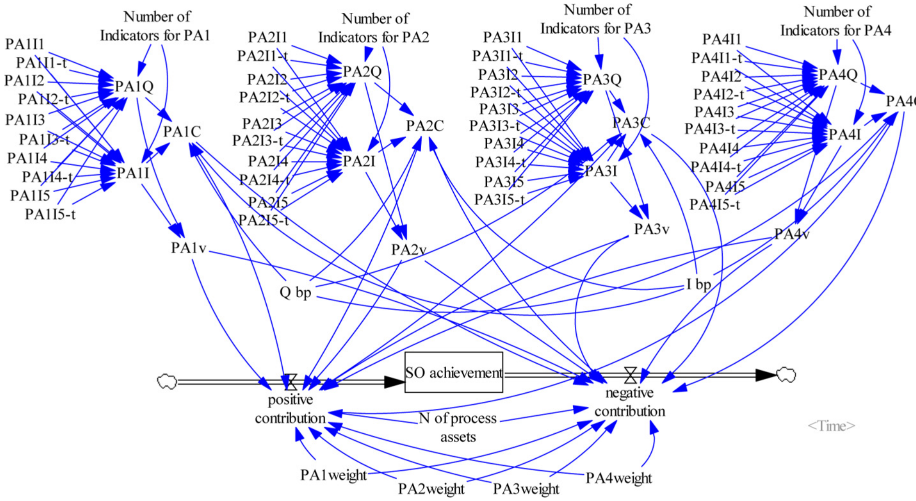

Figure 4.
System dynamics model for intangible asset characterization

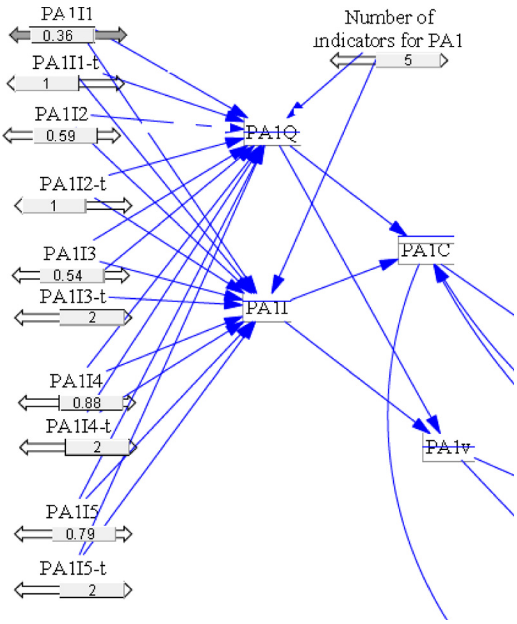

Figure 5.
Interactive system dynamics model: extract for PA1

The characterization of intangible assets is implemented in this model through the interaction between "auxiliary" (as they are referred to by the simulation tool) variables. The notation used for representing the variables is *PAiIj* for indicator *j* of the intangible process asset *i*, *PAiI* for the impact valuation of the intangible process asset *i*, *PAiQ* for the quality valuation of the intangible process asset *i* and *PAiC* for the characterization of the intangible process asset *i*.

In this system dynamics model, the characterization is given by dynamically assigning state-quadrant numbers to the *PAiC* variable. The possible numbers for the characterization are 1, 2, 3 and 4 as in a coordinate plane, where the first quadrant corresponds to stable PAs, the second to replaceable PAs, the third to warning PAs and the fourth to evolving Pas (Figure 2).

The characterization given by the system dynamics model is shown in Figure 6. The representation of each PA is equally spaced on the horizontal axis. The vertical axis shows the numbers corresponding to the characterization referred to in Figure 2. In this way, the characterization for each of the intangible PAs is shown from the left to the right. The characterization is given by the height of the representative line in the chart presented in Figure 2. The characterizing number for each intangible asset is shown on the vertical axis. The options are 1, 2, 3 or 4.

Figure 6 shows that PAs have been characterized according to the rules shown in Figure 2. PA1 has been characterized as 4 (evolving), PA2 as 1 (stable), PA3 as 3 (warning) and PA4 as 1 (stable).

4. Modelling and simulation tools for knowledge governance

Table I analyses and compares the NetLogo (Wilensky, 2012) and Vensim (Ventana Systems, 2011) simulation tools according to different criteria related to the management of strategic objectives and their usability in a strategic context.

Observations based on experience with the above models and approaches listed in Table I give an overview of how suitable and useful it is to undertake a knowledge management study based on simulation techniques.

5. Emerging properties: summarizing benefits

Modelling and simulation tools have in this research empowered the characterization of the intangible PAs from a broad and enveloping perspective. A strategic study that used to be a mechanical, step-by-step procedure has evolved into a dynamic and interactive process. This process helps stakeholders to quickly gain valuable and useful information that used to be hidden and obscure. Any stakeholder, from a company's CIO to a consultant interested in knowing the real state of the firm, can now juggle with the model by changing input parameter

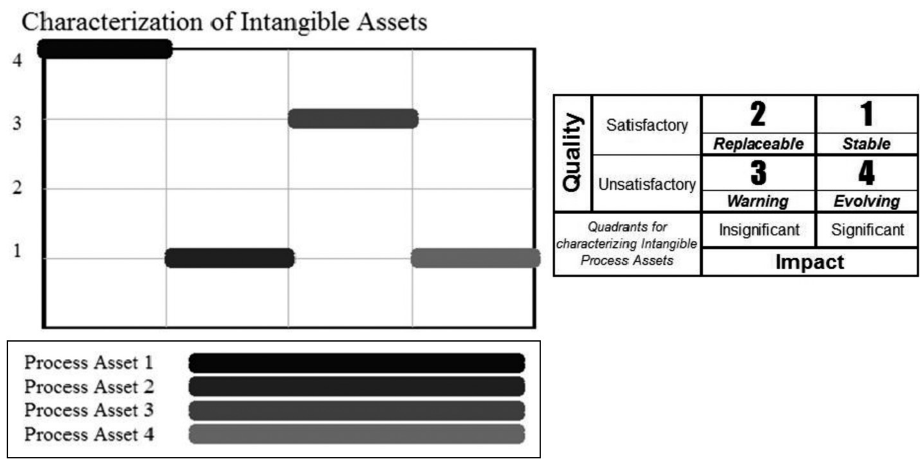

Figure 6.
System dynamics characterization

Table I.
Criteria comparing system dynamics and agent-based approaches in the domain of intangible assets

Criterion	Agent-based simulation (NetLogo)	System dynamics (Vensim)
Tool usability	Using NetLogo, it is easy to draw and represent the model elements; however, it requires high-level programming skills in a specific language and is time consuming	Although it is very useful for rapidly and quite effortlessly relating complicated programming elements, it takes a long time to configure image generation to cater for specific interests. In fact, it is rather hard to generate
Representation of PA indicators	Using NetLogo, it is possible to implement indicators using sliders that users find easy to handle	Indicator implementation is hard and impractical; however, Vensim provides the SyntheSim functionality that converts variables to sliders for instantly evaluating parameter variation throughout the entire model
Dynamic manipulation of parameters	Parameters can be easily manipulated using agent-based tools through sliders and numeric implementations of model variables	In system dynamics, parameters must be manipulated by modifying the internal configuration of the model elements. This is impractical
Generation of PA wellness reports	Instead of generating reports, the simulation window displays all the related information. The displayed information is strong enough to support decision-making	Vensim provides reactive information in several ways. A graph showing the characterization was created; however, Vensim has default functionalities to generate information on implemented variable relations, functions and properties, flows and levels
Modifiability	Model changes are not easy to implement because the implemented programming code has to be thoroughly verified and fine-tuned	Model changes are practicable if there is thorough knowledge of the model. Even minor changes to the structure would lead to changes to several small but "hidden" pieces of internal code in related elements
Requirement of specific knowledge	At least moderate experience in a high-level programming language is required. Structured, documented and understandable code has to be written, for which purpose good programming practices are very useful. A systemic perspective is required to understand complexity and relations between different elements of the system	Although programming skills are required, Vensim helps to structure and separate pieces of code. Some experience in systemic approaches would appear to be important to help construct a systemic view of the problem at hand: the dynamics of relation indicators – PAs – strategic objectives
Generation of graphs and support information	Graphs and information are evident while the model is being used. A lot of information emerges while the model is being manipulated. It provides important input for stakeholders of the system being "simulated"	Information is generally gathered by interpreting graphs representing the dynamics of model flows and stocks. This can be gathered after "simulation"
Extent of use in strategic contexts	It is easier to use in non-engineering contexts. Most of the mathematical and technical information is hidden, and the user can focus on practical information emerging from the model	A specific engineering context is required to be able to manipulate and modify model variables and elements. Some specific background in model use may even be necessary

values and graphically visualize how the characterization of the intangible PAs changes as a result. This offers a powerful and informative view of the characterization of intangible assets as a dynamic "whole" (because all the intangible PAs are presented as a set making up the company's entire know-how). It strongly contrasts with the original way of conducting these strategic studies, where a spreadsheet, and at best an expensive application, was often used to change the values manually by adjusting equations and configuring the target output. This procedure frequently caused error propagation and gave only a partial, non-dynamic view of the characterization process and its respective visual outputs.

By using either of these simulation-based tools, it is also possible to focus on one intangible asset as part of this "whole" represented by the model, and explore how it interacts with or is affected by others. This provides clues and valuable information that would not otherwise emerge. The agent-based model clearly designates each intangible asset by means of a colour and position. This is eye-catching and easily interpretable by non-specialist, thus widening the range of people who can benefit from the application of agent-based simulation tools in studies of the intangible PAs. The SD model denotes the characterization for each intangible PA by means of a number. This is not as graphically attractive for the human eye as the agent model. However, it does provide an alternative for users who could benefit from exploring the manifold causalities of the intangible PAs present in the system and the multiple connections that have not been pinpointed by any other strategic study. Both models provide important decision-making inputs regarding the intangible PAs and their behavior and performance with respect to related strategic objectives. Therefore, any stakeholder can examine these models, take the information and juggle with the model and generate simulated scenarios that would otherwise be impossible or very expensive to explore. Although specific knowledge is required to build or modify the simulation models, most interested people would need little training in the use and manipulation (not the construction or modification) of the models. This appears to be affordable if compared to the benefits that it would generate.

While traditional balance sheets show numerical information, these simulation models provide graphical information about the dynamics of the whole system. These models are an alternative way of discussing the behavior of intangible assets, their current status and, more importantly, what possible states and scenarios could emerge in response to changes made to the system. These are a non-expensive, affordable, reusable and systemic, thus enriching, approach.

6. Conclusions and future work

Although modelling and simulation tools were not initially conceived for use in the context of intangible assets measurement, this research has demonstrated how useful they are for representing the dynamics, relations and interactions of intangible assets with respect to a strategic objective and generating valuable graphs and visual reports for decision-making, strategy meetings and discussions regarding the interests of companies.

The agent-based simulation and system dynamics approaches have led to a more creative conception of intangible assets. As usually conceived, intangible assets are passive elements that are hardly ever taken into account in general-purpose performance reports and balance sheets. With these systemic approaches, intangible assets can be not only represented but also rethought as biomimetic elements with an active or assertive rather than a merely passive behaviour. This would result in significant improvements and inputs to the knowledge management field and the spectrum of uses and utilities of modelling and simulation approaches.

Knowledge-intensive organizations are dynamic and unquestionably complex. This brings with it an important array of opportunities for experimenting with systemic approaches. In this case, modelling and simulation tools were successfully used to gain a better understanding and representation of the complexity of knowledge-intensive systems. However, there is room for significant improvement in the near future by extending this research to other systemic approaches such as organizational cybernetics and soft systems studies. This would focus on developing unexplored closed loops and feedbacks.

This research has highlighted that knowledge management, intellectual capital and process improvement are new application domains for systems thinking. Future research will focus on collecting data about and documenting improvement processes and implementations of real knowledge dynamics in organizations, as well as exploring the dynamics and causalities present in dynamic decision-making tasks with respect to the PAs. One priority, for example, will be to discover how organizations implement changes based on knowledge valuation as specific actions, how long it takes to propagate the effects of these actions, how people manage and transfer their knowledge and how decisions are made by learning from past experiences.

The use of the modelling and simulation prism has helped to make definite progress towards understanding the phenomena occurring in organizational knowledge management. Indeed, it is now clear that systemic approaches, like the ones used in this research, are much more effective for helping to understand such complex systems. Intangible assets are complex, dynamic elements that appear to interact with each other and depend on human action for operation. In such a scenario, a systemic approach is a better problem-solving strategy.

As general scope for future research, modelling and simulation techniques appear to be appropriate for designing and testing the intelligent organizations of the future. Complexity related to the organizations of the future could become unmanageable and unintelligible. Therefore, simulation techniques for representing such complexity and juggling with related scenarios will provide a good research approach in pursuit of creating and promoting the emergence of evolutionary and adaptive organizations in the near future.

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