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Abstract. Business Ecosystems supported by the increasing use and expansion of communication networks represent nowadays a powerful form of collaboration, enabling organizations better responding to more challenging business opportunities. In this context, performance indicators are needed for measuring collaboration benefits of a business ecosystem as a whole and of its individual members, the organizations. But such indicators may also induce a self-adjustment of the organizations' behavior, as there is a natural tendency of individuals and organizations to adapt to the way they are evaluated. As such, an adequate selection of performance indicators can help the sustainability of the ecosystem. The level of reaction to indicators is nevertheless not the same for all members of the ecosystem, i.e. there are different classes of responsiveness. Using system dynamics and multi-agent systems, the focus of this paper is the study of the evolution of the agents of a collaborative business ecosystem, depending on the performance indicators used to assess their performance and considering their class of responsiveness.

Keywords: Collaborative Networks, Business Ecosystem, Performance Indicators.

1 Introduction

Nowadays, as the world is getting further interlinked via technological platforms, business ecosystems represent a new era of business environments. The term Business Ecosystem was introduced by Moore [1], [2] as a metaphor inspired by natural ecosystems. Moore also stated that in a business ecosystem *"companies co-evolve capabilities around a new innovation: They work cooperatively and competitively to support new products, satisfy customer needs, and eventually incorporate the next round of innovations.*" [1]. On the other hand, the research area of Collaborative Networks (CN) [3], which has a broader scope, identifies a business ecosystem as a form of CN, i.e. a case of Virtual organizations Breeding Environment (VBE), allowing a better understanding of its structure, lifecycles, endogenous characteristics, and exogenous interactions. As such, based on [4] and as defined in [5], a

collaborative business ecosystem (CBE) can be modeled as an environment of agents, representing the organizations, which collaborate creating virtual organizations (VOs) to accomplish business opportunities.

Collaboration is expected to benefit both the participants of a CBE and the CBE as a whole. But the collaborative behavior of agents is likely to be influenced by the performance indicators adopted by the CBE. Thus, selecting a proper set of performance indicators for CBEs is of particular importance. In this work, a simulation model is proposed to study the evolution of a CBE when exposed to evaluation through a given set of indicators.

The remaining sections of this paper are organized as follows: section two presents the proposed performance indicators and metrics to be used for the CBE evaluation, acting as a mechanism of influence in the behavior of the organizations; section three presents the hypothesis proposing a performance assessment and adjustment model to address it; section four presents a simulation scenario using elements of agent-based modeling and system dynamics [6]. The last section discusses the contributions and future work.

2 Performance Indicators and Metrics for CBEs

Performance evaluation is an important issue being used in various fields, particularly in the business area, with the balanced score cards (BSC) [7] being the most well-known mechanism for individual organizations. However, for the present research we are interested on collaboration benefits and metrics, for which only limited contributions can be found in literature. As an example, in [8] an estimation model for business benefits in horizontal collaborative networks is proposed for product development. Another example suggests a set of collaboration benefits identifying cooperation variables and the corresponding target goals [9]. Another contribution for this research, is a conceptual model for value systems in collaborative networks [10], which suggests methods to assess the alignment of value systems of different members of a network [11]. For the case of supply chain collaboration there is a great multiplicity of metrics and methods, as found in [12], [13], [14] and [15], some of which can be adopted for collaborative networks in general and for CBEs in particular. Finally, the area of social network analysis provides a well-established set of metrics of structural network analysis, which can also contribute to CBEs assessment, namely as in [16] and [17].

The performance indicators described in the next sub-sections, were chosen based on a previous literature analysis [18], and considering their relevance according to the dynamics and trends of current business environments [19]. Business ecosystems enable collaboration among multiple actors, the organizations, which diversity and collective ability leverage new ways to innovate and create value for society. The proposed performance indicators address these concerns by measuring the innovation due to collaboration, the new collaboration opportunities brought in or gained from the CBE, and the distribution of the collaboration among organizations in the CBE. These measures are expected to influence the organizations in self-adjusting their

behavior, improving their performance and thus improving the CBE as a whole by promoting its sustainability.

Innovation Indicator. The Innovation Indicator (II_i) of an individual organization, member of a CBE, measures the potential of the organization to create new products, services or patents. The result is a ratio between the number of new products and the portfolio of the organization. Metrics and calculations for II_i are described in Table 1.

The Innovation Indicator of the whole CBE (II_{CBE}) sums the innovation potential of all organizations in the CBE. The resulting ratio is then weighted by the correlation (Spearman's or Pearson's) [20] between the number of collaborations (#VOs), and new products, services or patents (#NewPds) created. Metrics and calculations for II_{CBE} are described in Table 2.

Table 1. Innovation Indicator for an individual organization.

Innovation Indicator (II_i)	
Measures the innovation potential of a member of the CBE	
$O_1,\ldots,O_n$	Organizations in the CBE
METRICS	
$\#PortPd_i$	Portfolio of products/services/patents of the member O_i
$\#NewPd_i$	Number of new products/services/patents generated by the member O_i
PERFORMANCE INDICATORS	
$II_i = \frac{\#NewPd_i}{\#PortPd_i}$	Is calculated by the ratio between the two metrics #NewPd$_i$ and PortPd$_i$

Note: II_i is a ratio

Table 2. Innovation Indicator of the whole CBE.

Innovation Indicator (II_{CBE})	
Measures the innovation potential of the CBE as a whole	
CBE	Whole CBE
METRICS	
$\{\#VO_1, \ldots, \#VO_n\}$	No. of VOs in which the members $O_1, \ldots, O_n$ participated
$\sum_i \#PortPd_i$	Total portfolio of products, services, or patents of the CBE
$\{\#NewPd_1, \ldots, \#NewPd_n\}$	No. of new products, services, or patents generated by the members $O_1, \ldots, O_n$
$\sum_i \#NewPd_i$	Total no. of new products generated in the CBE
PERFORMANCE INDICATORS	
$II_{CBE} = \frac{\sum_i \#NewPd_i}{\sum_i \#PortPd_i} * r(\#VO, \#NewPd)$	The ratio of the totals is weighed by the correlation r between the two metrics #VO and #NewPd

Note: II_{CBE} is a ratio weighted by a correlation

Contribution Indicator. The Contribution Indicator (CI_i) of an individual organization member of a CBE measures the capacity of the organization to create value, which is brought in or gained from the CBE's new collaboration opportunities. Metrics and calculations for CI_i are described in Table 3.

The Contribution Indicator of the whole CBE (CI_{CBE}) is calculated by two indicators, the ratio of the total number of collaboration opportunities created in the CBE by the number of organizations in the CBE, and the degree to which the most active member exceeds the contribution of the others. Metrics and calculations for CI_{CBE} are described in Table 4.

Table 3. Contribution Indicator for an individual organization.

Contribution Indicator (CI_i)	
Measures the contribution for value creation of a member of the CBE	
$O_1,\ldots,O_n$	Organizations in the CBE
METRICS	
#CoOp$_i$ in	No. of collaboration opportunities the member O_i gained from the CBE (indegree)
#CoOp$_i$ out	No. of collaboration opportunities the member O_i brought in the CBE (outdegree)
Act in/out(O_i)	Activity in/out of the member O_i in the CBE Act(O_i) can be measured by the weighted indegree/outdegree centrality (C_D) of the member O_i in the CBE, which stands for the sum of direct connections in/out of the member O_i to the n members O_j with weight #CoOp$_{ij}$ $Act\ in/out(O_i) = C_D\ (O_i)\ in/out = \sum_j O_{ij} \#CoOp_{ij}\ in/out$
PERFORMANCE INDICATORS	
$CI_i = (CI_i\ in, CI_i\ out)$	Is calculated by two indicators
Where, $CI_i\ in = \frac{\sum_j O_{ij} \#CoOp_{ij}\ in}{\max C_D(O_i)\ in}$	$CI_i\ out = \frac{\sum_j O_{ij} \#CoOp_{ij}\ out}{\max C_D(O_i)\ out}$

Note: CI_i in and CI_i out are normalized values

Table 4. Contribution Indicator of the whole CBE.

Contribution Indicator (CI_{CBE})	
Measures the value creation of the collaboration in the CBE as a whole, and the degree to which the most active member exceeds the contribution of the others	
CBE	Whole CBE
METRICS	
$\sum_i$ **#O$_i$**	Number of organizations in the CBE
$\sum_i$ **#CoOp$_i$**	Total no. of collaboration opportunities created in the CBE
{#CoOp$_1$, …, #CoOp$_n$}	No. of collaboration opportunities in which the members O_1, …, O_n participated
Act(CBE)	Activity of the members of the CBE
	Act(CBE) can be measured by the weighted degree centrality (C_D) of the CBE as a whole, i.e. the sum of the differences between the activity of the most active member (O*) and that of all members of the CBE $Act(CBE) = C_D(CBE) = \sum_i [C_D(O^*) - C_D(O_i)]$ Where, $C_D(O_i) = \sum_j O_{ij} \#CoOp_{ij}$ $C_D(O^*) = max[C_D(O_i)]$
PERFORMANCE INDICATORS	
$CI_{CBE} = (CI_{CBE}t,\ CI_{CBE}d)$	Is calculated by two indicators
Where, $CI_{CBE}t = \frac{\sum_i \#CoOp_i}{\sum_i \#O_i}$	$CI_{CBE}d = \frac{\sum_i [C_D(O^*) - C_D(O_i)]}{\max C_D(CBE)}$

Note: $CI_{CBE}t$ is a ratio and $CI_{CBE}d$ a normalized value

Prestige Indicator. The Prestige Indicator (PI_i) of an individual organization member of a CBE measures the influence/prominence of a member of the CBE, i.e., the likelihood of the organization be contacted towards potential collaboration opportunities. Metrics and calculations for PI_i are described in Table 5.

The Prestige Indicator of the whole CBE (PI_{CBE}) measures the average difference between the most influent member and that of all members of the CBE. Metrics and calculations for PI_{CBE} are described in

Table 6.

Table 5. Prestige Indicator for an individual organization.

Prestige Indicator (PI_i)	
Measures the influence/prominence of a member of the CBE	
$O_1,\ldots,O_n$	Organizations in the CBE
METRICS	
#CoOp$_i$	No. of collaboration opportunities of the member O_i participated in the
#CoOp$_{kj}$	No. of collaboration opportunities of the member O_{kj} participated in the
Inf(O_i)	Influence of the member O_i in the CBE, i.e., the likelihood of O_i to be contacted towards potential collaboration opportunities Inf(O_i) can be measured by the weighted betweenness centrality (C_B) of the member O_i in the CBE, assuming that connections between any member O_k and any other O_j have weight of #CoOp$_{kj}$ $Inf(O_i) = C_B(O_i) = \sum_k \sum_j O_{kj}(O_i)$ $\quad k < j,\ k \neq j \neq i$
PERFORMANCE INDICATORS	
$PI_i = \frac{\sum_k \sum_j O_{kj}(O_i)}{\max C_B(O_i)}$ $\quad k < j,\ k \neq j \neq i$	

Note: PI_i is a normalized value

Table 6. Prestige Indicator of the whole CBE.

Prestige Indicator (CI_{CBE})	
Measures the average difference between the most influent member and that of all members of the CBE	
CBE	Whole CBE
METRICS	
{#CoOp$_1$, …, #CoOp$_n$}	No. of collaboration opportunities in which the members O_1, …, O_n participated
$\sum_i$ **[Inf(O*) - Inf(O_i)]/(n-1)**	Average of the differences between the influence of the most influent member and that of all members of the CBE
Inf(CBE)	Influence of the members of the CBE Inf(CBE) can be measured by the weighted betweenness centrality (C_B) of the CBE as a whole, assuming that connections between any member O_k and any other O_j have weight of #CoOp$_{kj}$ $Inf(CBE) = C_B(CBE) = \sum_i [C_B(O^*) - C_B(O_i)]$ Where, $C_B(O_i) = \sum_i [C_B(O^*) - C_B(O_i)]$ $C_B(O^*) = \max[C_B(O_i)]$
PERFORMANCE INDICATORS	
$PI_{CBE} = \frac{\sum_i [C_B(O^*) - C_B(O_i)]}{\max C_B(CBE)}$	

Note: PI_{CBE} is a normalized value

3 Modeling a System for Performance Assessment of a CBE

The purpose of the indicators introduced in the previous section is anchored in the following hypothesis:

> *Performance indicators are a useful mechanism for assessing a CBE if they can contribute as a factor of influence for organizations to evolve, self-adjusting their behavior, and thereby improving the ecosystem performance and sustainability.*

To verify the hypothesis, a CBE can be seen as a closed environment where organizations live, interact and collaborate with each other to realize business opportunities. The organizations are characterized by an endogenous behavior which can be influenced by the adopted performance indicators to evaluate the CBE (assessment engine). Then, according to the purpose of each indicator, organizations react differently depending on the characteristics of their profile which react to a set of factors of influence. As an example, organizations in a highly competitive and innovative CBE are likely to have a higher responsiveness to the innovation indicator. On the other hand, organizations in healthcare service delivery are more likely to respond to indicators of contribution and quality. In addition, organizations with a similar profile may react with different intensity to the same factors of influence, allowing the establishment of classes of responsiveness.

For the present study, considering the assumptions described above, we propose a Performance Assessment and Adjustment Model (PAAM) as depicted in Fig. 1. The purpose of this model is to explore the impact of indicators in the assessment of organizations in a CBE, namely how they can influence an improvement of behavior, thus contributing for a better performance of the CBE.

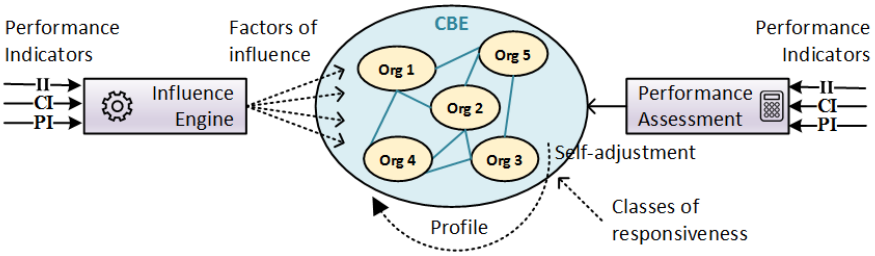

Fig. 1. PAAM (Performance Assessment and Adjustment Model) for a CBE.

4 Modeling an Evaluation Scenario

In order to study the above ideas, the proposed PAAM was implemented as a system based on simulation, using agent-based modeling (ABM) and system dynamics (SD). ABM is used for simulating the actions and interactions of the autonomous organizations (the agents) in the CBE (the environment). SD is a mathematical

modeling method to enhance learning in complex systems, supporting simulation models which help to understand the dynamics of complexity, allowing designing more effective policies and organizations [21]. Discrete elements (statecharts, events, timers, etc.) can be used to combine the different techniques and models [22], controlling state transitions, delays, or even capture exogenous values.

4.1 Setting-up the Simulation Model

Fig. 2 illustrates the designed PAAM simulation system, where the organizations are autonomous agents, operating and collaborating in an environment which represents the business ecosystem. A system dynamics model simulates the evolution of the behavior of the organizations (and the CBE as a whole). This behavior is influenced by a mechanism of evaluation, i.e., when assessed according to the proposed performance indicators (II, CI, and PI).

When a new business opportunity is acquired by an organization (Org_i), it is brought in the CBE as a new collaboration opportunity (CoOp), which triggers the creation of a virtual organization (VO) formed by a set of selected candidate organizations (the partners). The selection is based on the required competencies (matching skills) for that collaboration opportunity, and a ranking of the organizations according to a set of attributes which characterize their profile (attributes such as innovation index, accomplishment index, quality assurance index, and reputation index). These indexes (could be more) were selected for the simulation model, since they are directly related to the adopted performance indicators, i.e., when the CBE is evaluated through the calculation of the proposed performance indicators, this assessment is expected to induce some self-adjustment of the organizations' profile, as there is a natural tendency of individuals and organizations to adapt to the way they are evaluated. Thus, the performance indicators act as factors of influence, causing different responses according to the profile and class of responsiveness of the organizations. For instance, as suggested in Fig. 2, the II influences de innovation index, the CI is more related to the accomplishment and quality assurance indexes, and the PI influences the reputation index.

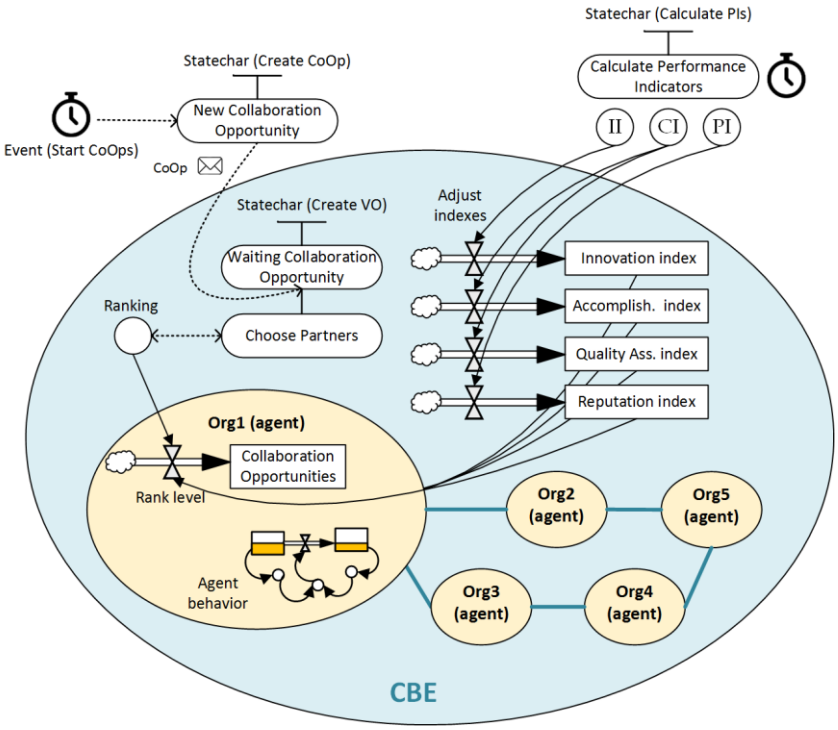

Fig. 2. General schema of the simulation PAAM system.

4.2 Setting-up the Simulation Scenario

To set-up a complete simulation scenario to study de evolution of a CBE when assessed by the proposed performance indicators, we need to focus on the agent's behavior. The agent's behavior is modeled by system dynamics, and can represent a concern or a problem of the organization, as the generic example based on [21], depicted in Fig. 3.

The example in Fig. 3, comprising a causal loop diagram, aims to explore the causes of late delivery for an organization's design work [21]. The model shows the behavior of a team of engineers trying to conclude the tasks of a project against a deadline. The shorter the time remaining, the more schedule pressure they feel. When the pressure is high, the team has several choices. If they work overtime, the completion rate increases, thereby decreasing the number of remaining tasks and easing the schedule pressure (balancing loop B1). However, after a certain time, productivity drops due to fatigue, lowering the completion rate and increasing again the schedule pressure (reinforcing loop R1). Another way to meet the deadlines is to devote less time to each task, which increases the productivity as more tasks are done. Consequently, the schedule pressure is relieved (balancing loop B2), but the quality assurance is neglected, causing more faults, lowering productivity and forcing more scheduled pressure (reinforcing loop R2).

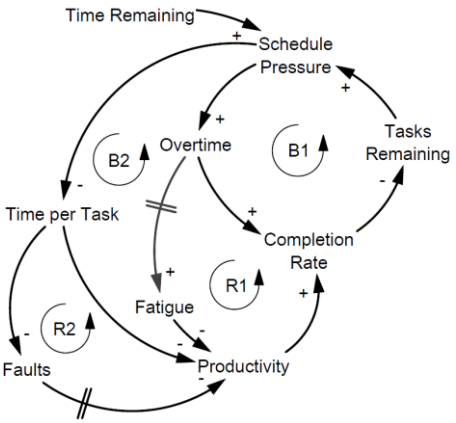

Fig. 3. Behavior of a team trying to complete a project against a deadline (based on [21]).

To complete the simulation scenario, the behavior of the agents, as the example illustrated in Fig. 3, should be expressed by a stock and flow map coupled to the PAAM system. Fig. 4 depicts a zoom in one organization (Org_1) showing the corresponding agent's behavior. The factors of influence and class of responsiveness should be parametrized for each agent.

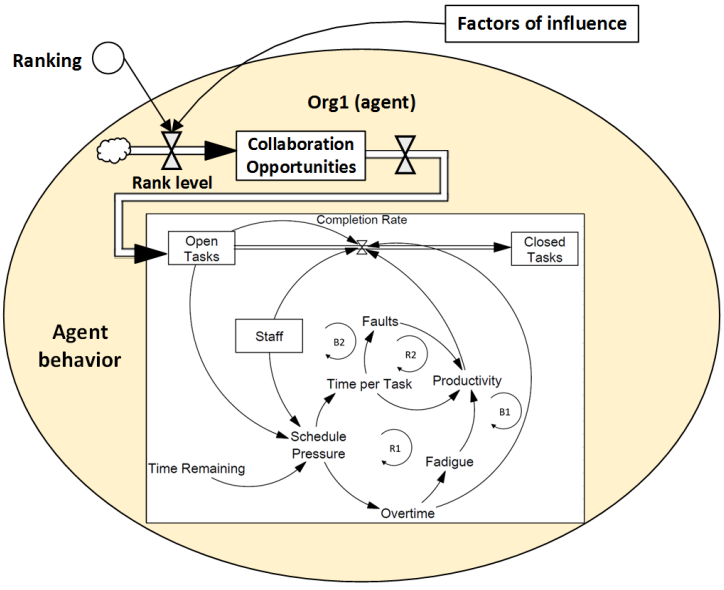

Fig. 4. Zoom in one organization (Org_1), showing the corresponding agent's behavior in a stock and flow map (based on [21]).

The ongoing work is focused on completing the development of the PAAM system using AnyLogic Multimethod Simulation Software [22], a tool that supports discrete

event, agent based, and system dynamics simulation. The objective is setting-up a simulation scenario as described above, representing a CBE with organizations with different profiles (implying different factors of influence), and classes of responsiveness. By varying these parameters, it is expected that the model will allow understanding the evolution of the behavior of the organizations, namely their self-adjustment as a reaction to the assessment through the proposed performance indicators, and then verifying if that contributes for the improvement of both the organizations and the CBE as a whole.

5 Conclusions and Further Work

The performance indicators and metrics for CBEs presented in this paper, as well as the proposed PAAM system, contribute as a first approach to verify the hypothesis stated in section three, providing a simulation model to study the evolution of organizations in a CBE influenced by a given set of performance indicators. As such, the model is designed to allow identifying the indicators that lead to an improvement of the behavior of the organizations, thus improving the CBE and its sustainability.

The ongoing work, as mentioned above, comprises finishing the creation of the proposed PAAM system using AnyLogic Multimethod Simulation Software [22], to allow the configuration of multiple simulation scenarios, where the organizations in a CBE are represented by an ABM (agents in an environment), and the autonomous behavior of the organizations, by SD. "*System dynamics seeks endogenous explanation for phenomena.*" [21]. The "interactions" between the agents and the variables, factors of influence, and responsiveness, are expected to provide a mechanism to study the effects of different sets of indicators.

The future work is aimed to continue the next steps of the modeling process [21]. i.e., after the problem articulation, dynamic hypothesis, and formulation, covered in the presented approach, comes next the testing phase, and the policy design and evaluation phase. The testing phase will consider concerns such as boundary adequacy, structure and parameter assessment, extreme conditions, behavior reproduction and anomaly, sensitivity analysis, among others. Finally, the policy design and evaluation phase allows designing and evaluating policies for improvement.

Thus, the proposed PAAM system, configured using several scenarios and parametrizations, is expected to reveal important insights, to make us understand the dynamics and evolution of a CBE when assessed by a given set of indicators.

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