A Model of Evolution of a Collaborative Business Ecosystem Influenced by Performance Indicators

Paula Graça[1,2(✉)] and Luis M. Camarinha-Matos[1(✉)]

[1] Faculty of Sciences and Technology and Uninova CTS, NOVA University of Lisbon, Campus de Caparica, 2829-516 Caparica, Portugal
cam@uninova.pt

[2] Instituto Superior de Engenharia de Lisboa, Instituto Politécnico de Lisboa, Rua Conselheiro Emídio Navarro 1, 1959-007 Lisbon, Portugal
mgraca@deetc.isel.pt

Abstract. The materialization of the 4th Industrial Revolution needs to emphasize the role of collaboration. Traditional business ecosystems have evolved to hyper-connected organizations facing more advanced collaboration models, dynamic networks, and more complex smart systems. Emerging collaborative aspects in this context need to be identified, and tools developed to help organizations coping with changing environment, market, and societal needs. As such, an assessment model is proposed to measure the expected self-adjustment of organizations in a collaborative business ecosystem, induced by performance indicators, in order to improve the organizations themselves and the ecosystem as a whole. Organizations with distinct profiles, categorized by classes of responsiveness, respond differently to the collaboration opportunities they may receive, or are more likely to invite others to collaborate. This behaviour is expected to be influenced by the variation in importance (weight) of each specific performance indicator adopted in a given business ecosystem, as the organizations, like individuals, tend to evolve according to how they are evaluated. To assess the proposed approach, an experiment has been set up using a simulation model based on system dynamics and agents. Preliminary results, based on a number of relevant scenarios, are presented and discussed.

Keywords: Collaborative Networks · Business ecosystem · Performance indicators · System dynamics · Agent based modelling

1 Introduction

Business ecosystems are continuously evolving, accompanying the growing use of digital and collaborative platforms. Nowadays, they are shifting towards the age of Industry 4.0, more specifically to the notion of Collaborative Industry 4.0 [1]. The expression Business Ecosystem was first introduced by Moore and inspired by ecological ecosystems [2]. On the other hand, a business ecosystem it is also considered in the research area of Collaborative Networks (CN) [3], which has a wider scope.

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As such and aiming to emphasize the collaboration dimension, the term Collaborative Business Ecosystem (CBE) has been introduced in [4] and a model proposed [5].

The aim of the present work is to assess the influence of performance indicators in a CBE, expecting to improve its behaviour and that of its individual organizations. There are several mechanisms to evaluate organizations individually, of which the balanced score cards (BSCs) [6] are the best-known. However, to evaluate collaboration benefits, only limited contributions can be found in the literature. As an example, [7] proposes a conceptual model for value systems in CNs, and suggests a method for assessing the alignment of the value systems of their members [8]. Other examples in the field of supply chain collaboration (SCC), a relatively new research area that is growing fast [9], identify collaboration to improve performance in traditional SCs and propose a wide variety of methods and metrics in [10–12]. Finally, the social network analysis (SNA) proposes a set of metrics related to the structure of the network, namely in [13] and [14], consisting of the most adequate approach as a contribution to the establishment of the performance indicators of the CBE.

For the evaluation of the CBE in this work, two of the performance indicators proposed in [5] and [15] (CI – Contribution Indicator and PI – Prestige Indicator) are detailed, as well as a proposal for an influence mechanism. For experimental assessment, the CBE is simulated by a Performance Assessment and Adjustment Model (PAAM) as proposed in [5], using agent based modelling (ABM) and system dynamics (SD) [16].

The remaining sections of this paper are organized as follows: section two describes the proposed simulation model, presenting its collaborative and assessment environment; section three shows how to calculate two of the performance indicators used to illustrate the assessment; section four presents the experimental evaluation of the model using a parametrized scenario to assess and verify the influence of indicators in its evolution, including a discussion of results. The last section summarizes the results and identifies the ongoing research and future work.

2 A Simulation Model of a CBE

The PAAM model illustrated in Fig. 1, simulates a CBE environment populated by organizations (the agents) of different profiles, classified according to classes of responsiveness described in Table 1, thus allowing the establishment of diversified behaviors. To better respond to market opportunities, it is assumed that organizations collaborate by creating collaboration opportunities (*CoOps*) that they send and receive from each other. These collaborations generate "links" between organizations, weighted by the number of times they collaborate (*#CoOps*). The higher values of *#CoOps* mean stronger collaboration.

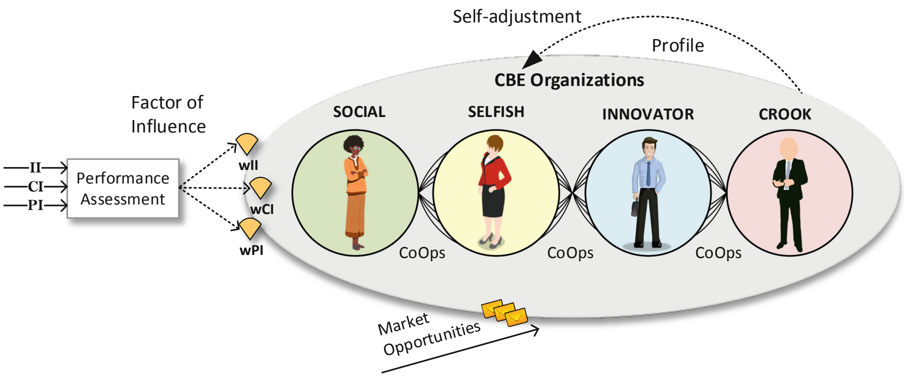

Fig. 1. PAAM (Performance Assessment and Adjustment Model) for a CBE.

For a certain CBE, a variable number of organizations of each class of responsiveness can be used among those considered in Table 1: Social, Selfish, Innovator, and Crook, to better reproduce diversity in a true CBE. Each class is composed of three parameters to characterize the agents, whose values presented in Table 1 are merely illustrative and can be adjusted for each simulation scenario. These parameters (decimal values ranging from 0 to 1), are used as the probability of successful attempts in the distribution functions adopted by the model to simulate the random behaviour of the agents.

Table 1. Description of the classes of responsiveness of organizations.

Classes of responsiveness of organizations					
	Parameters [0..1]	Social	Selfish	Innovator	Crook
Contact rate	Willingness to invite others to collaborate	0,8	0,1	0,4	0,3
Accept rate	Readiness to accept invitations	0,7	0,2	0,5	0,3
New products rate	Tendency to accept opportunities related to innovation	0,2	0,2	0,9	0,3

2.1 Collaborative Environment

When an organization wants to collaborate with other organizations in the CBE, it requests so by sending a *CoOp* (*taskDescription*, *resourcesToAssign*), describing the task and specifying the amount of resources assigned. This amount is given by a binomial distribution as illustrated in formula (1), to get a value bounded between [0, *resourcesToAssign*] with a probability equal to the *contactRate* parameter. The higher the parameter, the more likely it is to get more resources to distribute. Organizations belonging to the Social class have the highest *contactRate* and those of the Selfish class the lowest.

$$contact_{to_{collaborate}} = binomial(contactRate, resourcesToAssign) \tag{1}$$

On the other hand, the organizations that receive the invitations, if having available resources, accept with a probability given by the Bernoulli distribution [17] as illustrated in formula (2). The result is "yes/no" with the "yes" having a probability equal to the *acceptRate* parameter. The higher the parameter, the more likely the collaboration is to be accepted. Organizations belonging to the Social class also have the highest *acceptRate* and those of the Selfish class the lowest.

$$accept_{collaboration} = bernoulli(acceptRate)\ \&\&\ resourcesAvailable \tag{2}$$

Finally, if the *CoOp* refers to a task related to innovation, which may result in the development of new products or patents, then the organizations also accept the collaboration according to the Bernoulli distribution as illustrated in formula (3), but with a probability equal to the *newProductsRate* parameter. The higher the parameter, the more likely the collaboration is to be accepted. Organizations belonging to the Innovators class have the highest *newProductRate* and those of the Social and the Selfish class the lowest.

$$accept_{collaboration} = bernoulli(newProductsRate)\&\&\ resourcesAvailable \tag{3}$$

2.2 Assessment Environment

A performance assessment mechanism can be used to assess the CBE and its individual organizations, based on the indicators proposed in [5] and [15]: the Innovation Indicator (II), to evaluate the proficiency of the organizations to create new products or patents; the Contribution Indicator (CI), to evaluate the value generated by the collaboration; and the Prestige Indicator (PI), to evaluate the prominence of a particular organization over others, to participate in collaboration.

The weight (significance) given to each performance indicator by the CBE manager, is expected to act as a factor of influence, resulting in a certain achievement of organizations, which as individuals, tend to adjust according to the way they are evaluated. For demonstrative purposes, a scenario of simulation was created with three main components of common business activity: research and development (R&D), Consulting, and Inner tasks. For the realization of each component, the organizations allocate a given percentage of resources according to their class of responsiveness. Table 2 illustrates a sample of a possible allocation used in the current experiment (the Crook class was not considered).

Table 2. Sample of resources allocation by business activity and class of responsiveness.

Resources allocation				
Activity	Social	Selfish	Innovator	Crook
R&D	10%	10%	30%	N/A
Consulting	70%	60%	60%	N/A
Inner tasks	20%	30%	10%	N/A

It is assumed that the variation in the weights of the performance indicators by the CBE manager, will act as a factor of influence over the organizations, causing their self-adjustment trying to improve their profile, resulting in an improvement of the CBE as a whole. Therefore, as illustrated in Fig. 2, it is considered that an influence mechanism acts on the percentage of resources allocated to each business activity, called respectively *slice for R&D*, *slice for Consulting* and *slice for InnerTasks*. The factor of influence (FI) of the mechanism, is expressed as a percentage (for instance 10%) of improvement to be distributed among the slices according to the weights of the performance indicators (*wII*, *wCI* and *wPI*), causing a reallocation of resources and a consequent self-adjustment of the organizations' behaviour. It is also assumed that the resources for R&D are influenced by the weight *wII*, and the resources for consulting, are influenced by the weights *wCI* and *wPI*.

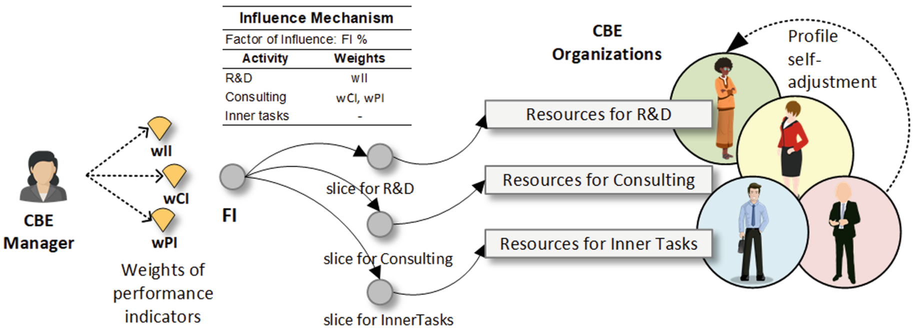

Fig. 2. Detail of the influence mechanism used for the presented simulation model.

Considering the resources allocation of Table 2 as a base distribution, the influence mechanism can be expressed by formulas (4), (5) and (6).

$$slice_{forR\&D} = slice_{forR\&D_{base}} - \frac{FI}{3} + \frac{wII * FI}{wII + wCI + wPI} \tag{4}$$

$$slice_{forConsulting} = slice_{forConsulting_{base}} - \frac{FI}{3} + \frac{(wCI + wPI) * FI}{wII + wCI + wPI} \tag{5}$$

$$slice_{forInnerTasks} = slice_{forInnerTask_{base}} - \frac{FI}{3} \tag{6}$$

According to these formulas, the influence mechanism subtracts the FI equally from the three slices of resources, so that it can be redistributed by considering the weights of the indicators.

3 Performance Indicators to Assess the Influence on the CBE

Two of the performance indicators proposed in [5], are used in this work to assess the CBE and the influence on the behaviour of its organizations in terms of collaboration. The Contribution Indicator (CI),to measure the total value created by collaboration in the CBE as a whole and that of its individual organizations, and the Prestige Indicator (PI), to measure the influence/prominence of the organizations in the CBE.

Tables 3 and 4 describe the metrics used to calculate the performance indicators CI and PI, of the organizations' collaboration and that of the CBE as a whole.

Table 3. Metrics of the Contribution Indicator.

Metrics of the Contribution Indicator (CI)	
Metric	Description
$O_{1,\ldots,}O_n$	Organizations in the CBE
#O	Number of organizations in the CBE
$\#CoO_{pi}$ in	No. of collaboration opportunities the organization O; gamed from the CBE
$\#CoO_{pi}$ out	No. of collaboration opportunities the organization O; brought in the CBE
$\sum_i \#CoO_{pi}$	Total no. of collaboration opportunities created in the CBE
$C_D(O_i)$ in/out	Weighted indegree/outdegree centrality (C_D) of the organization O_i in the CBE, which stands for the sum of direct connections in/out of O_i to the n organizations O_i, with weight $\#CoOp_{ij}$
$C_D(O^*)$ in/out	Maximum indegree/outdegree centrality of O_i

The CI_i *in* of an organization, assesses the contribution of the organization O_i in terms of accepted collaboration opportunities. The value CI_i *in* is thus obtained by the weighted degree centrality of O_i calculated by formula (7), which is more related to the popularity of organizations [18].

$$CI_i in = \frac{C_D(O_i)in}{C_D(O^*)in} = \frac{\sum_j O_{ij}\#CoOp_{ij}in}{\max \sum_j O_{ij}\#CoOp_{ij}in} \tag{7}$$

The CI_i *out* of an organization, assesses the contribution of the organization O_i in terms of created collaboration opportunities. The value CI_i *out* is thus obtained by the weighted outdegree centrality of O_i calculated by formula (8), which is more related to the activity of organizations [18]. These values are normalized between 0 and 1 in relation to the maximum degree centrality for the current network.

$$CI_i out = \frac{C_D(O_i)out}{C_D(O^*)out} = \frac{\sum_j O_{ij}\#CoOp_{ij}out}{\max \sum_j O_{ij}\#CoOp_{ij}out} \quad (8)$$

The CI_{CBE} *in* and the CI_{CBE} *out* of the CBE, assess respectively the degree to which the most popular organization in terms of accepted collaboration opportunities and the most active organization in terms of created collaboration opportunities, exceeds the contribution of the others. The values CI_{CBE} *in* and CI_{CBE} *out* are thus obtained by the weighted degree centrality of the CBE as a whole calculated by formulas (9) and (10), i.e. the sum of differences between the contribution of the most popular/active organization (O^*) and that of all organizations in the CBE. These values are normalized between 0 and 1 in relation to the maximum possible sum of differences of degree centralities for the current network.

$$CI_{CBE}in = \frac{C_D(CBE)in}{maxC_D(CBE)in} = \frac{\sum_i [C_D(O^*)in - C_D(O_i)in]}{C_D(O^*)in * (\#O - 1)} \quad (9)$$

$$CI_{CBE}out = \frac{C_D(CBE)out}{maxC_D(CBE)out} = \frac{\sum_i [C_D(O^*)out - C_D(O_i)out]}{C_D(O^*)out * (\#O - 1)} \quad (10)$$

The $CI_{CBE}t$, calculated by formula (11), is a ratio of the total number of collaboration opportunities created in the CBE by the total number of organizations.

$$CI_{CBE}t = \frac{\sum_i \#CoOpi}{\#O} \quad (11)$$

Table 4. Metrics of the Prestige Indicator.

Metrics of the Prestige Indicator (PI)	
Metric	Description
$O_{1,\ldots,}O_n$	Organizations in the CBE
#O	Number of organizations in the CBE
$\#CoO_{pi}$ in	No. of income collaboration opportunities the organization O_i participated in the CBE
$\#CoO_{pi}$ out	No. of outcome collaboration opportunities the organization O_i participated in the CBE
$\#CoO_{pkj}$ in/out	No. of income/outcome collaboration opportunities between the organization O_k and O_j in the CBE
$C_B(O_i)$ in/out	Weighted income/outcome betweenness centrality (C_B) of the organization O_i in the CBE, which stands for the sum of overall partial betweenness of O_i relative to all pairs O_{kj}, assuming that connections between O_k and O_j have weight of $\#CoO_{pki}$
$C_B(O^*)$ in/out	Maximum income/outcome betweenness centrality of O_i

The PI_i *in* of an organization, assesses the prominence of the organization O_i in terms of accepted collaboration opportunities. It means the extent to which a node (organization) is part of transactions (collaboration) among other nodes [18]. Using Freeman's betweenness measure [13], this means the number of times that an organization is on the shortest paths among all pairs of the other organizations. In a binary network, the shortest path means the smallest number of intermediate nodes between two organizations. However, in weighted networks, the transactions (collaboration) between two nodes (organizations) might be faster (more expressive) with more intermediate nodes that are strongly connected [18]. This is due to the fact that stronger intermediate nodes mean more collaboration between organizations. The value PI_i *in* is thus obtained by the weighted betweenness centrality calculated by formula (12), which stands for the sum of overall partial betweenness of O_i relative to all pairs O_{kj} assuming that connections between any O_k organization and any other O_j have weight of $\#CoOp_{kj}$ *in*.

$$PI_i in = \frac{C_B(O_i)in}{C_B(O^*)in} = \frac{\sum_k \sum_j O_{kj}(O_i)in}{\max \sum_k \sum_j O_{kj}(O_i)in} \tag{12}$$

The PI_i *out* of an organization, assesses the prominence of the organization O_i in terms of created collaboration opportunities. Similarly to PI_i *in*, PI_i *out* is calculated by formula (13). These values are normalized between 0 and 1 in relation to the maximum betweenness centrality for the current network.

$$PI_i out = \frac{C_B(O_i)out}{C_B(O^*)out} = \frac{\sum_k \sum_j O_{kj}(O_i)out}{\max \sum_k \sum_j O_{kj}(O_i)out} \tag{13}$$

The PI_{CBE} *in* and PI_{CBE} *out* of the CBE, assess respectively the degree to which the most prominent organization in terms of accepted collaboration opportunities and the most prominent organization in terms of created collaboration opportunities, exceeds the contribution of the others. The values PI_{CBE} *in* and PI_{CBE} *out* are thus obtained by the weighted betweenness centrality of the CBE as a whole calculated by formulas (14) and (15), i.e. the average of the differences between the preponderance of the most influent organization ($O*$) and that of all organizations in the CBE. These values are normalized between 0 and 1 in relation to the maximum possible sum of differences of betweenness centralities for the current network.

$$PI_{CBE} in = \frac{C_B(CBE)in}{maxC_B(CBE)in} = \frac{\sum_i [C_B(O^*)in - C_B(O_i)in]}{C_B(O^*)in * (\#O - 1)} \tag{14}$$

$$PI_{CBE} out = \frac{C_B(CBE)out}{maxC_B(CBE)out} = \frac{\sum_i [C_B(O^*)out - C_B(O_i)out]}{C_B(O^*)out * (\#O - 1)} \tag{15}$$

The PI indicator, as shown in formulas (12), (13), (14) and (15), uses the betweenness centrality to evaluate the preponderance of organizations' collaboration in the CBE. For this, the Floyd-Warshall algorithm [19] was applied to find the shortest paths in the weighted graph represented by the CBE and its organizations connected by collaboration opportunities. The algorithm starts with a distance matrix *D* with *n lines* and *n columns*, where *n* is the number of nodes (*#O*) and each position of the matrix *D[i, j]* contains the weight ($\#CoOp_{ij}$) between the node *i* (O_i) and node *j* (O_j).Because the shortest paths in the CBE mean stronger connections between the organizations, i.e. more collaboration, the inverse of the $\#CoOp_{ij}$ is used, resulting in the matrix (16).

$$D^n = \left\{ \begin{array}{cccc} \infty & \frac{1}{\#CoOp_{0,1}} & \cdots & \frac{1}{\#CoOp_{0,n-1}} \\ \frac{1}{\#CoOp_{1,0}} & \infty & \cdots & \frac{1}{\#CoOp_{1,n-1}} \\ \frac{1}{\#CoOp_{2,0}} & \frac{1}{\#CoOp_{2,1}} & \cdots & \frac{1}{\#CoOp_{2,n-1}} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \frac{1}{\#CoOp_{n-1,0}} & \frac{1}{\#CoOp_{n-1,1}} & \cdots & \infty \end{array} \right\} \quad (16)$$

The shortest paths matrix is then obtained after *k = 0..n−1* iterations over the D^n distance matrix, where in each *k* iteration, the D^k matrix is calculated according to formula (17).

$$D^n_{ij} = \min\left(D^{n-1}_{ij}, D^{n-1}_{ik} + D^{n-1}_{kj}\right) \quad (17)$$

Finally, to compute the betweenness centrality of each node, i.e. the number of times that an organization O_i is on the shortest paths among all pairs of the other organizations O_{kj}, the Floyd-Warshall algorithm [19] had to be improved. A path matrix *P* was used to register the shortest paths between all pairs, starting with the matrix P^0 calculated according to (18).

$$P^0_{il} = \left\{ \begin{array}{c} null\ if\ i = j\ or\ D_{ij} = \infty \\ i\ in\ all\ other\ cases \end{array} \right. \quad (18)$$

The final P^n matrix is reached after *k = 0..n−1* iterations, where in each *k* iteration, the P^k matrix is calculated according to formula (19).

$$P^n_{ij} = \left\{ \begin{array}{c} P^{n-1}_{ij}\ if\ D^{n-1}_{ij} < D^{n-1}_{ik} + D^{n-1}_{kj} \\ P^{n-1}_{ij} \cup P^{n-1}_{kj}\ if\ D^{n-1}_{ij} = D^{n-1}_{ik} + D^{n-1}_{kj} \\ P^{n-1}_{kj}\ if\ D^{n-1}_{ij} D^{n-1}_{ik} + D^{n-1}_{kj} \end{array} \right. \quad (19)$$

All the metrics and formulas described in this chapter, were used to calculate the performance indicators in the experimental evaluation of the CBE.

4 Experimental Evaluation of the CBE

To build the proposed PAAM described in Sect. 2, for the experimental evaluation of the CBE, and to implement the performance indicators described in Sect. 3, the AnyLogic Multimethod Simulation Software [16] was used. The model depicted in

Fig. 3, simulates an environment (the CBE), populated by agents (the organizations), whose behaviour is represented by state-charts and system dynamics, to represent stocks and flows of resources.

The income market opportunities (*incomingMarketOps*) are also modelled by agents arriving at a rate of 1.000/year plus a 25% of opportunities for new products or patents, following the Poisson distribution (adequate for modelling the number of times an event occurs in an interval of time) [20]. Each *incomingMarketOps* is composed of a task description (research or consulting) and a number of resources (days-man) estimated to perform the task (generated by a uniform distribution bounded by [1..50 days-man]).

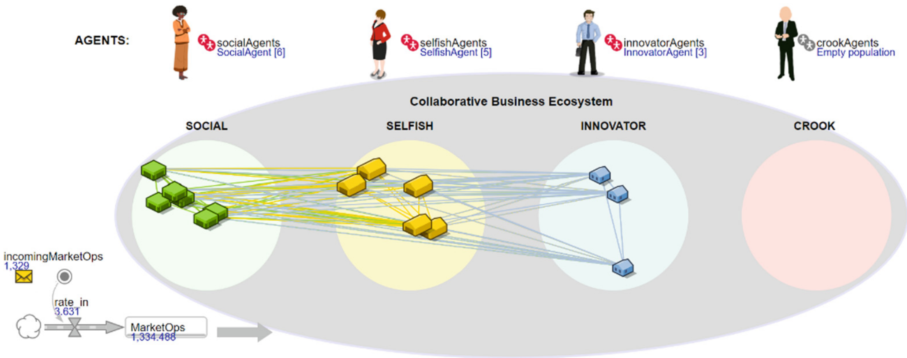

Fig. 3. PAAM model after an iteration of one year.

The organizations, whose profile is differentiated by classes of responsiveness, respond to *incomeMarketOps* interacting by sending and receiving collaboration opportunities (*CoOps*). To fulfil the tasks, the available resources are consumed according to the type of business activity (*R&D*, *Consulting* or *Inner tasks*) and the amount of estimated resources. The influence mechanism of the Fig. 2 induces a reallocation of resources causing a self-adjustment in the profile of the organizations.

For the present experimental evaluation, the PAAM simulation model was parametrized to represent a CBE composed of 6 Social organizations, 5 Selfish and 3 Innovative. The organizations were configured with the values described in Tables 1 and 2, having an initial amount of resources of 1.500/year (day-man).

Running the model considering the interval of one year, the performance indicators CI and PI were calculated, resulting in the values displayed in Table 5. Columns CI_i *in* and CI_i *out* show respectively the contribution of the organization O_i in terms of accepted *CoOps*, and the contribution in terms of created *CoOps* by inviting other organizations to collaborate. On the other hand, columns PI_i *in* and PI_i *out* show respectively the prominence of the organization O_i, i.e. the extent to which O_i is part of the collaboration among the other organizations in terms of accepted or invited *CoOps*. Finally, the performance indicators related to the whole CBE, have the following results: $CI_{CBE}t$ = 26,4 is the ratio of the total number of *CoOps* generated in the CBE by the total number of organizations; CI_{CBE} *in* = 0,444 and CI_{CBE} *out* = 0,214, are respectively the degree to which the most popular organization (*#CoOps* received) and the most active (*#CoOps* created), exceeds the contribution of the others; PI_{CBE} *in* = 0,776 and PI_{CBE} *out* = 0,686, are respectively the degree to which the most prominent organization (being part of the *CoOps* received or created) exceeds the contribution of the others.

Table 5. Values of the CI and PI for each individual organization and for the CBE.

Contribution and Prestige Indicators (CI and PI)				
Class of Resp.	CI_i in	CI_i out	PI_i in	Pl_i out
Social	0,89	0,97	1,00	0,83
	0,58	1,00	0,44	0,63
	0,64	0,76	0,17	0,12
	0,76	0,64	0,17	0,33
	0,82	0,82	0,68	0,97
	0,71	0,70	0,16	0,21
Selfish	0,20	0,58	0,00	0,00
	0,27	0,85	0,00	0,00
	0,20	0,94	0,33	0,33
	0,20	0,73	0,00	0,00
	0,22	0,79	0,00	0,00
Innovator	0,76	0,85	0,71	1,00
	1,00	0,94	0,54	0,96
	0,98	0,67	0,01	0,01
	Cl_{CBE} t	26,4		
	CI_{CBE} in	0,444	PI_{CBE} in	0,776
	CI_{CBE} out	0,214	PI_{CBE} out	0,686

The indicators CI_{CBE} *in/out* reveal a better distribution of the collaboration than the PI_{CBE} *in/out*, since these values are normalized between 0 and 1, with zero indicating an equal distribution of collaboration among all organizations.

Running the model again for a period of one year and parameterizing the influence mechanism as shown in Table 6, the results of Table 7 were achieved.

Table 6. Parametrization of the influence mechanism.

Influence mechanism			
Factor of influence	Weights		
Fl	wll	wCI	wPI
10%	1	4	2

Comparing the results of Tables 5 and 7, it can be observed that the more significant difference in the CBE after applying the influence mechanism, is that all the organizations tried to be more active creating more *CoOps*. The indicator $CI_{CBE}t$ increased from 26,4 to 26,7 (showing a higher average of collaboration opportunities by organization, although not very significant), and the CI_i *out*(invites to collaborate sent by organization) also increased for almost all the organizations, flattening CI_{CBE} *out* from 0,214 to 0,178 (showing a more uniform collaboration among organizations) at the same time. On the other hand, the PI_i *in* also had an increase (more prestige concerning invitations received) but only in the Social and Innovator classes, resulting in a better PI_{CBE} *in* from 0,776 to 0,742 (showing a more uniformization of the prestige among organization), but still showing a high polarized distribution. Finally, no further significant differences were registered.

Table 7. Values of the CI and PI for each individual organization and for the CBE, after the influence mechanism.

Contribution and Prestige Indicators (CI and PI)				
Class of Resp.	CI_i in	CI_i out	PI_i in	PI_i out
Social	0,85	1,00	1,00	0,77
	0,55	1,00	0,45	0,57
	0,62	0,81	0,22	0,15
	0,72	0,66	0,22	0,36
	0,79	0,88	0,76	0,99
	0,66	0,78	0,18	0,21
Selfish	0,21	0,56	0,00	0,00
	0,26	0,91	0,00	0,00
	0,21	0,97	0,33	0,33
	0,17	0,78	0,00	0,00
	0,23	0,81	0,00	0,00
Innovator	0,72	0,88	0,79	1,00
	1,00	0,97	0,71	0,98
	0,96	0,69	0,15	0,02
	CI_{CBE} t	26,7		
	CI_{CBE} in	0,465	PI_{CBE} in	0,742
	CI_{CBE} out	0,178	PI_{CBE} out	0,687

Although the previous observed responses of a CBE and its individual organizations, to the proposed influence mechanism are not very significant so far, these are preliminary results using arbitrary parameters so that the modelling and simulation concept can be illustrated. Other improvements to the influence mechanism should be made as well as the adjustment of the parameters used in order to obtain more meaningful conclusions.

5 Conclusions and Further Work

The PAAM model and the experimental evaluation in the previous section showed that a CBE can be evaluated through performance indicators, more specifically, the proposed CI and PI. It also showed that a CBE can evolve by self-adjusting of the behaviour of its organizations, when influenced by the variation of the weights (significance) of the adopted performance indicators.

The ongoing work is related to the improvement of the influence mechanism, enhancing the calculation formulas by introducing more variables in addition to the allocated resources.

Future work includes the calculation of the Innovation Indicator (II), correlating it with collaboration. On the other hand, the PAAM model should be more dynamic, basing the decision to collaborate not on distribution functions, but depending on the performance of organizations. Finally, more refined and tested simulation scenarios should be carried out using all classes of responsiveness with different and dynamic parametrizations.

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References

1. Camarinha-Matos, L.M., Fornasiero, R., Afsarmanesh, H.: Collaborative networks as a core enabler of Industry 4.0. In: Camarinha-Matos, L.M., Afsarmanesh, H., Fornasiero, R. (eds.) PRO-VE 2017. IAICT, vol. 506, pp. 3–17. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-65151-4_1
2. Moore, J.F.: Predators and prey: a new ecology of competition. Harvard Bus. Rev. **71**(3), 75–86 (1993)
3. Camarinha-Matos, L.M., Afsarmanesh, H.: Collaborative networks: a new scientific discipline. J. Intell. Manuf. **16**(4–5), 439–452 (2005)
4. Graça, P., Camarinha-Matos, L.M.: The need of performance indicators for collaborative business ecosystems. In: Camarinha-Matos, L.M., Baldissera, T.A., Di Orio, G., Marques, F. (eds.) DoCEIS 2015. IAICT, vol. 450, pp. 22–30. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-16766-4_3
5. Graça, P., Camarinha-Matos, L.M.: Evolution of a collaborative business ecosystem in response to performance indicators. In: Camarinha-Matos, L.M., Afsarmanesh, H., Fornasiero, R. (eds.) PRO-VE 2017. IAICT, vol. 506, pp. 629–640. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-65151-4_55
6. Kaplan, R.S., Norton, D.P.: The Balanced Scorecard: Translating Strategy into Action. Harvard Business Press, Brighton (1996)
7. Camarinha-Matos, L.M., Macedo, P.: A conceptual model of value systems in collaborative networks. J. Intell. Manuf. **21**(3), 287–299 (2010)
8. Macedo, P., Camarinha-Matos, L.M.: A qualitative approach to assess the alignment of value systems in collaborative enterprises networks. Comput. Ind. Eng. **64**(1), 412–424 (2013)

9. Ramanathan, U.: Performance of supply chain collaboration – a simulation study. Expert Syst. Appl. **41**(1), 210–220 (2014)
10. Vereecke, A., Muylle, S.: Performance improvement through supply chain collaboration in Europe. Int. J. Oper. Prod. Manag. **26**(11), 1176–1198 (2006)
11. Lorentz, H., et al.: Supply chain collaboration performance metrics: a conceptual framework. Benchmarking Int. J. **18**(6), 856–872 (2011)
12. Ramanathan, U., Gunasekaran, A.: Supply chain collaboration: impact of success in long-term partnerships. Int. J. Prod. Econ. **147**, 252–259 (2014)
13. Freeman, L.C.: Centrality in social networks conceptual clarification. Soc. Netw. **1**(3), 215–239 (1978)
14. Jackson, M.O.: Social and Economic Networks, vol. 3. Princeton University Press, Princeton (2008)
15. Graça, P., Camarinha-Matos, L.M.: A proposal of performance indicators for collaborative business ecosystems. In: Afsarmanesh, H., Camarinha-Matos, L.M., Lucas Soares, A. (eds.) PRO-VE 2016. IAICT, vol. 480, pp. 253–264. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-45390-3_22
16. Borshchev, A.: The Big Book of Simulation Modeling: Multimethod Modeling with AnyLogic 6. AnyLogic North America, Chicago (2013)
17. JHCW: Introduction to mathematical probability. Sci. Prog. **33**(130), 350–350 (1938). (1933)
18. Opsahl, T., Agneessens, F., Skvoretz, J.: Node centrality in weighted networks: generalizing degree and shortest paths. Soc. Netw. **32**(3), 245–251 (2010)
19. Floyd, R.W.: Algorithm 97: shortest path. Commun. ACM **5**(6), 345 (1962)
20. Haight, F.A.: Handbook of the Poisson Distribution. Wiley, New York (1967)