Methods for Assessing the Maturity Levels of Software Ecosystems

Svitlana Popereshnyak [1[0000-0002-0531-9809]], Sergiy Grinenko [2[0000-0001-5544-2605]], Olena Grinenko [3[0000-0001-9673-6626]], Oleksandr Kovalenko [3[0000-0001-9297-0650]], Tamara Radivilova [4[0000- 0001-5975-0269]]

[1] Taras Shevchenko National University of Kyiv, Kyiv, Ukraine
spopereshnyak@gmail.com
[2]National Aviation University, Kyiv, Ukraine
[3]Central Ukrainian National Technical University, Kropivnitskiy, Ukraine
[4]Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
serggrin@ukr.net, gsa_ck@ukr.net

Abstract. This article is devoted to the development of method for assessing the maturity of software ecosystems. This method for assessing the levels of maturity of software ecosystems and for calculation the duration of the projected period required to reach a maturity level are described here also. The article deals with the approach to the study of software ecosystems that uses fuzzy set theory to construct a software ecosystem maturity assessment tool. Features of use and calculation of the given methods are considered. Known models of maturity of information ecosystems are considered, namely, qualitative models of CMMI, COBIT, OPM3, Kerzner model and quantitative Berkeley model. A 3-tier maturity model of software ecosystems is shown. The method for estimating the maturity levels of software ecosystems is presented.

Keywords: software ecosystem, maturity model, maturity levels, method, IT enterprises.

1 Introduction

The object of our research is software ecosystem. This domain of software ecosystems has become quite popular in the last decade. The concept of software ecosystem is widely used today, but to date there is no formal definition of this concept. Existing domain studies represent only a verbal and descriptive concept. Analysis of existing sources has shown that the concept of software ecosystems can be viewed from different perspectives, which gives rise to different classifications and characteristics of ecosystems. This article uses the software ecosystem definition that is given in [1]: "…software ecosystem as a set of businesses functioning as a unit and interacting with a shared market for software and services, together with the relationships among them. These relationships are frequently underpinned by a common technological platform or market and operate through the exchange of information, resources and artifacts".

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The subject of research is the maturity of software ecosystems, as well as the models and methods used to research maturity levels and their qualitative assessment.

To achieve this goal there were considered the latest scientific publications of the last 5 years, which were publicly available. The following studies should be noted.

In [2] there was introduced a maturity model for software startup ecosystems based on systematic qualitative research around a multiple case study across three ecosystems. The study was carried out over 4 years and included an extensive array of data collection mechanisms such as literature reviews, expert interviews, and observations in three relevant ecosystems (Tel-Aviv, São Paulo, and New York); all collected data were analyzed with techniques based on Grounded Theory, resulting in a conceptual framework of software startup ecosystems. Also, there was developed a maturity model for startup ecosystems, which helps understand their evolution and dynamics.

The model, which is presented in [3], deals with the software ecosystem governance maturity model (SEG-M2), which has been designed along the principles of a focus area maturity model. The SEG-M2 has been designed for software producing organizations to assess their ecosystem governance practices, set a goal for improvement, and executes an improvement plan.

In [4] there were discussed challenges connected with agile software ecosystems. For each challenge there were identified the following properties: the ecosystem's maturity, the phase within the agile lifecycle, other influencing factors, and causes for the respective challenge.

The results of these researches deal with quantitative analysis of software ecosystem maturity and its levels. Unfortunately, there is no qualitative analysis of the relevant characteristics. Thus, the relevance of this study is generated by the need to develop a method for qualitatively assessing the maturity of software ecosystems.

Today is no doubt in the need to use information systems and information technology in enterprise management. It allows the management of any company to make the right and timely strategic decisions, even in the most difficult situations, when it is necessary to operate a large amount of information. However, not always the use of these information management tools is cost – effective for the use of the enterprise. Therefore, effectiveness evaluation of information systems and information technology is a necessary procedure for any enterprise that uses them [6-12].

2 The Maturity Model of Software Ecosystems

Each company in its own activities goes through certain stages of staff development, formulation of goals, choice of strategies, changes in organizational structure and project management technologies and more.

Obviously, some companies have much more experience in management, higher performance, more professional project teams than others, use innovations and so on. The above preconditions have led to the emergence of global developments in the identification of the organization from the standpoint of compliance with a certain model of maturity.

Under the models of maturity we understand a set of parameters that correspond to a certain stage of development of an organization.

In modern conditions, the concept of maturity of organizations focused on achieving competitive advantage is becoming increasingly important. Today there is a significant number of maturity models, the most popular of which are the following:

- Kerzner maturity model;
- Berkeley maturity model;
- ORM3 maturity model (Organizational Project Management Maturity Model);
- CMMI model (Capability Maturity Model Integration).

These models have many features in common. The main principle of their construction is the transition from a lower level of maturity (general awareness of the creation of the software ecosystem) to a higher level, which involves continuous improvement of processes in software ecosystems.

The authors propose a model of software ecosystem maturity, which is formed from the standpoint of 3 key levels of maturity: genesis, growth and maturity (fig. 1).

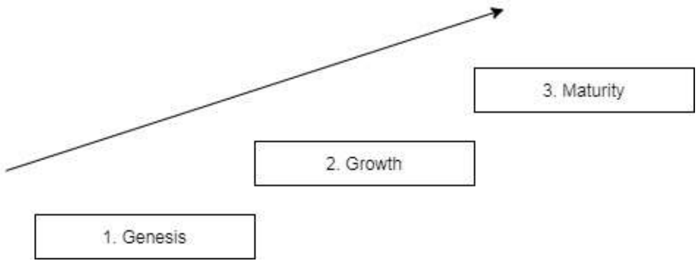

Fig. 1. Maturity Model of Software Ecosystem

The first level is characterized by the emergence of a general awareness of the need to apply an ecosystem approach to management, restructuring the organizational structure, improving the skills of staff in this area. The general corporate understanding of the need to apply an ecosystem approach to business activities leads to the following natural processes: the needs for financial and human resources for the implementation of this management are substantiated, the directions of formation of internal management standards are outlined, etc.

At the next level, the already existing elements of the ecosystem establish relationships with each other. New members of the network first interact with those members of the ecosystem that have the most connections and a certain "significance" in the community.

Finally, at the last level there is an expansion of the infrastructure to support innovative business, scaling and replication of the service system created at the previous stage, integration into existing technology chains and the creation of new ones based on international cooperation. Maintaining the achieved positions and the possibility of transition to higher levels of maturity requires the company to constantly improve.

An important task in achieving a certain level of maturity is to assess the current level of maturity of the software ecosystem. To achieve this purpose and depends on this ranges and type of software ecosystem, the following models can be used: CMM, CMMI, COBIT, OPM3, Kertsner model, Berkly model, etc. Any of these models can be used to assess maturity levels, but note that the above models focus on assessing the processes of organizations with developed maturity, which are not companies that are only going to use the ecosystem approach in their management. This makes it impractical to consider these models for such companies and to apply classical evaluation methods.

3 CMMI Method of Assessing the Maturity Levels of Software Ecosystems

For software ecosystems evaluation, it is proposed to use a maturity model of ecosystem member organizations in the field of CMMI. But the paper proposes the use of fuzzy set theory to construct an ecosystem maturity assessment tool.

In the CMMI maturity model, key practices are grouped into specific goals, then the goals are grouped in the CMMI process area [5]. Thus, it is advisable to use hierarchical systems of fuzzy inference to determine the level of maturity. Then the maturity of the ecosystem will be determined by the relation (1):

$$M = f\left(f_1(P_1, P_2, \dots, P_7), f_2(P_8, P_9, \dots, P_{18})\right), \tag{1}$$

where M is maturity of company, $f_1(), f_2()$ are functions for defining maturity for 2 and 3 levels, $P_1, P_2, \dots, P_{18}$ are assimilations of process areas in CMMI models.

Assimilations of each process area are determined by the relation (2):

$$P_i = h_i(g_{i1}(p_{i11}, \dots, p_{i1i}), \dots, g_{in}(p_{inm})), \tag{2}$$

where $h_i()$ is a function of fuzzy output of process area development with index *i*, $g_{ij}()$ is a function of fuzzy inference of achievement of IT companies of the *j* special purpose for the *i* process area, p_{ijk} is mastering the IT company of the *k* special practice of the CMMI model, which is included in the *j*-y special purpose for the *i* process area.

Let's determine the estimates NI, PI, LI, FI as fuzzy numbers given by fuzzy sets N, P, L, F on the set of real numbers R. Sets N, P, L, F are defined on the intervals of the set R – $[n_L, n_R], [p_L, p_R], [l_L, l_R], [f_L, f_R]$ accordingly. For each number NI, PI, LI, FI let's define on R membership functions $\mu_i(x)$ such as $\forall x \in R | \mu_i(x) \in [0,1]$, where $i \in \{N, P, L, F\}$.

$$\mu_i(x) = \begin{cases} left\begin{pmatrix} 0 \\ \frac{x-a_1}{a_2-a_1} \\ 1 \end{pmatrix}, \text{ де } a_1 \le x < a_2 \text{ – left side function } \mu_{i\uparrow}(x), & x < a_1 \\ & a_2 \le x \le a_3 \\ right\begin{pmatrix} 1 \\ \frac{a_4-x}{a_4-a_3} \\ 0 \end{pmatrix}, a_1 < x \le a_2 \text{ – right side function } \mu_{i\downarrow}(x). & x > a_4 \end{cases} \quad (3)$$

For the following fuzzy numbers the notion of metric between two numbers is defined:

$$d^2(a,b) = \int_0^1 (A_L(a) - B_L(a))^2 da + \int_0^1 (A_U(a) - B_U(a))^2 da, \quad (4)$$

Where fuzzy number is defined through the concept of $\alpha -$ intersection such as $\forall a \in [0,1] \; \exists \; a_1 \le x \le a_4$ and $\mu_a(x) \ge a$ and $A_L(a) = \mu_{a\uparrow}^{inv}(x)$ is inverse function $\mu_a(x)$ at the interval of its increase, and $A_U(a) = \mu_{a\downarrow}^{inv}(x)$ is inverse function $\mu_a(x)$ at the interval of its decrease.

To determine the reach of special purpose of IT companies and areas of the CMMI process, let's consider the function $f(x_1, x_2, \dots, x_n) = x_1 \oplus x_2 \oplus \dots \oplus x_n$, where operation $\oplus$ will be an operation of adding fuzzy numbers according to formula (5):

$$a \oplus b = \int_{a_1 \otimes b_1}^{a_2 \otimes b_2} \frac{\min(\mu_a(x), \mu_b(y))}{x \otimes y}, \quad (5)$$

where operation $\otimes$ is operation $+, \; -, \; \times, \; /$. The achievement of the specific goal of G_i in the development of the processes of the evaluated IT company is determined as linguistic characteristic: fully achieved (FR), partially achieved (PR), not achieved (NR).

In general, let's assume that the special goal G_i is achieved (FR) if the sum of the experts' answers to the question about the degree of implementation in the company of key practices, defined by the maturity model of the media, expressed as a fuzzy number equal to $f(x_1, x_2, \dots, x_n) = x_1 \oplus x_2 \oplus \dots \oplus x_n$, approaching fuzzy $FI * n = FI_1 \oplus \dots \oplus FI_n$.

The special goal G_i is partially achieved (PR) if $f(x_1, x_2, \dots, x_n) = x_1 \oplus x_2 \oplus \dots \oplus x_n$ approaches a fuzzy number $PI * n = \frac{LI*n \oplus PI*n}{2}$.

The special goal G_i is not reached (NR) if $f(x_1, x_2, \dots, x_n) = x_1 \oplus x_2 \oplus \dots \oplus x_n$, approaches a fuzzy number $NI * n = NI_1 \oplus \dots \oplus NI_n$.

The development of the process area is expressed as the sum of the $G_i$estimates of the type NR, PR, FR obtained in the previous step for the special purposes included in a specific area of the process of CMMI. The development of process areas is denoted by the linguistic variables NF, FF, PF, which will correspond to the concepts of "area not mastered", "partially mastered", "fully mastered". They will be calculated in general form according to the following rules:

- process area $F_i = PF$ if $\sum_{i=1}^{n} G_i$ approaches $\sum_1^n NR$;
- process area $F_i = PF$ if it approaches $\sum_1^n PR$;
- process area $F_i = PF$ if it approaches $\sum_1^n FR$;

Next, it is necessary to determine the development of IT company maturity levels. To do this, the functions $f()$, $f_1()$, $f_2()$ from equality (4) must be defined. But if the same considerations can be applied to the functions $f_1()$ and $f_2()$, express their result by the sum of the process areas mastered, then such considerations will no longer be appropriate for the function $f()$. In the CMMI model, a company is considered to reach level 3 (R) if it has reached Level 2 (D) and has, in most cases, mastered process areas specific to level 3. If the values of the functions $f_1()$ and $f_2()$ are determined by the term set $\{NM, PM, FM\}$ = {"genesis", "growth", "maturity"} then we can formulate such is a set of fuzzy rules:

If $f_1(P_1, \ldots, P_7) = NM$, then $M = I$.
If $f_1(P_1, \ldots, P_7) = PM$, then $M = D$.
If $f_1(P_1, \ldots, P_7) = FM$, then $M = D$.
If $f_1(P_1, \ldots, P_7) = PM$ and $f_2(P_8, \ldots, P_{18}) = NM$, then $M = D$.
If $f_1(P_1, \ldots, P_7) = PM$ and $f_2(P_8, \ldots, P_{18}) = PM$, then $M = R$.
If $f_1(P_1, \ldots, P_7) = FM$ and $f_2(P_8, \ldots, P_{18}) = PM$, then $M = R$.
If $f_1(P_1, \ldots, P_7) = FM$ and $f_2(P_8, \ldots, P_{18}) = FM$, then $M = R$.

These rules allow to develop a software tool for assessing the maturity of IT companies.

4 Methods for Assessing the Maturity Levels of Software Ecosystems

The software ecosystem maturity stages outlined in the previous section are related to assessing the potential to form ecosystems. Increasing the number of participants in software ecosystems and their types of activities affects the attractiveness of software ecosystems in the region and provides growth of its potential: the emergence and cooperation of new participants will lead to the creation of new companies, developments, innovative business models, etc., which will create a base for further development of territory.

There are currently no tools available to assess the maturity of software ecosystems, given the potential for innovation in the region. The use of existing techniques for assessing software ecosystem development is problematic because of the difficulty of data collection. In addition, they are focused only on the analysis of the number of connections between participants, the identification of concentrator participants (i.e. have the largest number of connections), etc., without affecting the problems of capacity assessment.

A variety of activities are required for software ecosystems to operate sustainably. The changes in the number of species and their composition determine the development of the ecosystem and influences the change of maturity stages. Thus, diversity is the key to the existence and development of software ecosystems.

The diversity of software ecosystems is characterized by the presence of rare (small number of companies) and large (large number of companies) activities. If there are rare species, many of them, under certain conditions, may develop mass activities. Thus, rare species form the potential of software ecosystems.

Thus, the analysis of the maturity of software ecosystems should be carried out in the light of the changing diversity of activities, because it affects the potential of the software ecosystems of the region.

Each software ecosystem has its own unique species composition, so diversity cannot be analyzed using data only on the number of species and the number of companies in species. An indicator for comparing software ecosystems of different regions in terms of rare and mass species is γ, which is determined on the basis of formula (6):

$$\Omega(x) = W_0 * x^{-\gamma}, \quad (6)$$

For the regions which are studying, the formation of this type of distribution, the following indicators are:

Ω(x) – the number of activities of the company size (number) x;

W(i) – the number of activities of the companies represented the i-th number of companies;

W_0=W(1) – the number of activities of companies, represented by unique species (each species is represented by a single company);

$W_0 = \frac{V}{\sum_x x^{-\gamma}}$ – normalization multiplier ;

V – total number of species;

x∈[1,∞] – continuous analogue of the number of species i, i = [x] (the number of companies (i = [x]), presented a certain number of species (W (i));

γ – indicator, measure of the ratio of rare and widespread species determined empirically.

Determined range for software ecosystem level, in our case from 0 to 1, includes the following intervals (classical mathematical intervals):

0-0.33 – The result is "Unsatisfactory",

0.34-0.66 – Result "Satisfactory",

0.67-0.79 – The result of "Good",

0.8-1 – The result of "Excellent".

The values of the first range show "Genesis" of software ecosystem, the next two determine "Growth" and the last one – "Maturity".

The following sequence of calculation of the indicator γ is offered:

1. Combining the activities of the companies, represented in equal numbers in groups.

2. The location of the obtained groups in ascending order of the number of activities.

3. Calculation of the indicator γ.

Graphically, the distribution of companies by rare and mass species is represented by hyperbole. When the number of rare and mass species is changed, the slope of the hyperbola changes: if the greater "deflection" (steepness), then the higher "gap" in rare and mass species. The change in the ratio is due to the correction of the number of species (their growth).

Because the software ecosystem is a dynamic system, the combination of rare and mass activities is constantly changing, so the value of γ is changing.

If γ characterizes diversity, it can be concluded that the dynamics of γ reflects the dynamics of diversity. Note that each stage of development of the software ecosystem is characterized by different trends in species and their numbers. This allows to conclude that diversity determines maturity, and the identified trends can be interpreted as characteristics of different stages of maturity of the software ecosystem. Thus, the positive dynamics of γ corresponds to the stage of “genesis” or “growth”, growth retardation – “maturity”, decrease – “decline”, and lack of dynamics – “stagnation”.

In addition to the indicator γ, diversity is also characterized by the introduction by the author of the diversity factor, which reflects the “saturation” of the activities of companies in the software ecosystem. This indicator allows us to identify the potential of regions: in software ecosystems at earlier stages of development, diversity is only increasing, so there are rare species and the potential is also growing. In such regions, the ratio is higher. The coefficient is calculated by the formula (7):

$$\text{Diversity} = \frac{\text{number of activities of companies in the region}}{\text{number of companies in the region}} \quad (7)$$

It means that over time, the coefficient decreases as the software ecosystem becomes mature and the number of activities does not increase as intensively as in the initial stages.

In combination with other indicators that affect the growth or reduction of diversity (the amount of venture funding, the number of companies) with this indicator it is possible to calculate the integrated assessment of the region on a given date and compare with other regions. After ranking the regions in descending order of the received assessment, a conclusion is made about the prospects of certain territories.

For the generalized characteristic of the region it is offered to define an integral indicator of development by the formula:

$$I = K1 * P1 + K2 * P2 + K3 * P3, \quad (8)$$

where I is an integral indicator of the region's development,

K_1 – weight of the criterion “venture financing”;

K_2 – weight of the criterion “companies financed by venture capital”;

K_3 – weight of the criterion “coefficient of diversity”;

P_1 – rating of the region in total funding;

P_2 – rating of the region in the total number of companies;

P_3 – rating of the region in the total coefficient of diversity.

The calculation of the integrated indicator is recommended to be carried out according to the specified criteria, taking into account the weights assigned by experts.

Estimation of time parameters necessary for the region to reach the target level of software ecosystem development is necessary to identify the period, after which the level of diversity of the region will approach the target, which is determined taking into account the peculiarities and objectives of the region. The choice of this criterion is explained by the fact that diversity determines the dynamics of the software ecosystem, and also has a relationship with the potential of the region [13-15].

To calculate the required period, the following method is proposed:

1. Determining the parameters of the linear trend $x(t) = a + b * t$, where t is the period of time required to achieve the level of the software ecosystem indicators of the advanced region taken for comparison, and $x(t)$ is the value of the diversity factor.

2. The calculation of the forecast period (t) is determined based on the equation, taking into account the change between the level of the target value of the coefficient of diversity $x'(t)$ and the actual $x(t)$ by the formula:

$$\Delta t = \Delta x / b, \quad (9)$$

where b is a parameter that characterizes the change in the coefficient of diversity per unit of the accepted time period.

5 Conclusions

To date, a large number of different methods to evaluate different processes in management have been developed. However, today, there is no single methodology that is suitable for assessing any enterprise. Therefore, there is a rather difficult problem with the right choice of a specific method of maturity assessment, which requires the management of companies to take a differentiated approach to each step.

This scientific paper is brief description of software ecosystem maturity evaluation, which will be hold continuation in future researches.

It is worth pointing out that construction of the maturity model of software ecosystem is quite a challenge. In the general case, such a system can have a large set of objects, and then there is a need in operational planning and not just planning, but optimal planning and management of tasks and access to its shared resources. There are many methods of building optimal planning and management. The difficulty in solving these problems is that, in the general case, these problems are objectively contradictory. This is the reason for the emergence of a large number of methods, because to successfully solve this type of problem, a certain level of abstraction is selected, for which appropriate methods are developed. This type of problem is most often formulated as an optimization problem, and then a method is developed to solve such a problem.

Further study of software ecosystems will be to explore approaches to solving the problem of planning the allocation of basic resources in the ecosystem, which are based on Petri nets, transition systems, time automata, and so on. That is, in the future a logical approach to the analysis of other properties of software ecosystems will be considered.

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