Collective Intelligence for Evaluating Synergy in Collaborative Innovation

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Abstract. Collaborative innovation is an unavoidable need for the small and medium enterprises (SME) both in terms of economic scale and technological knowledge. Risks and the innovation power are analyzed for the wealth of collaboration. This paper aims to present the *synergy index* as a multiplier of the innovation power of research partners to construct a successful collaboration. The proposed index can be used with different number of companies in collaboration cluster and the synergy maximization is guaranteed by using a new particle swarm algorithm, *Foraging Search*. This paper will give the formulation and criteria of the synergy index in detail. A sample synergy index application for the Turkish SMEs will clarify the steps to follow.

Keywords: Innovation, SME, Synergy, Clustering, Foraging Search.

1 Introduction

Recently an article published in Scientific American illuminated one of the main differences between the humans and the animals as sharing the knowledge to create cumulative culture [1]. Though it is recently biologically proven, we have been using the concept of synergy in engineering since the very first project developed to create a team work. In the last few years international projects are run in collaboration by public and private authorities causing studies and discussions on synergy and conflict [2]. Companies are obliged to innovate for competition and are willing to collaborate for the unique product/processes/service only after defining the team with bigger chance of success [3]. Small and medium companies (SME) would like to gratify the collaborative innovation with less risk.

The main approach in the synergy literature is the extraction of factors that affect synergy in alliances using case studies [4,5] or statistical analyses [6,7]. These studies recommend building alliances based on the criteria that have the biggest effect on collaborations. Further quantifications are achieved with Multi Criteria Decision Making, where partners are selected using the criteria extracted in previous studies [8]. In the existence of strict goals of alliances, a number of mathematical methods are built. Majority of the researchers have exploited and developed recent mathematical models involving the goal programming [9] and multi-objective programming [10].

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This study has the main objective of proposing a synergy index as a multiplier of the innovative power to be maximized for successful partnership. It will be presented that when both innovation capabilities and the risks are considered through internal and external influencers, the synergy created will avoid the failure. In order to determine the best team of companies, the possible companies are to be clustered based on all the criteria effective for synergy improvement. A collective intelligence approach, particle swarm optimization is selected to evaluate the collaborative synergy since it has the social component in parallel with the knowledge based evaluation [11]. However, the fact that the classical particle swarm method is based on balancing the exploration and exploitation at the particle level [12] would mean individual success of each company. An advanced new particle swarm algorithm, foraging search is based on creating balance of exploitation and exploration at the swarm level as well as particle level, which allows us to calculate the collaborative success [13].

This paper is distinguished and will make contribution to the research in three main points:

- Instead of choosing a partner as studied before, this study deals with grouping and clustering of the synergy creating SMEs.
- The criteria studied in this research combines the innovative power and risk criteria with the synergy which are depicted from the literature and selected by industrial experts.
- Algorithm used in this study is not based on a threshold as in goal programming, thus it allows the selection of partners even in vague and uncertain conditions.

This paper is so organized that a literature review on the collaborative innovation will be given in the next section and the synergy index function will be explained in the third section. Foraging Search algorithm that is used to maximize the synergy will be explained in the fourth section and the fifth section of the paper is reserved for the application. The conclusion and further suggestions will be summarized in the last section.

2 Synergy in Collaborative Innovation

Knowledge based collaboration is the fuel of innovation for the SMEs. They are known to be agile in change, but fragile in facing the economic fluctuations [14]. Collaborative innovation is mainly based on the synergy created by the partner companies. When it is on the virtual network an intelligent agent can take the role of a moderator. In private or public industries skill based clustering has been an effective tool to create synergy among the team workers [15,16]. However it is difficult to construct a creative task ground for the team members who come from different business cultures. Innovative capabilities of more than one company working together are established on both the knowledge and vision for internal and external alliance. Big companies succeed the collaboration by defining the performance focused on cross-business growth [17]. They might even improve the innovative capabilities by merger and acquisition [18]. SMEs on the other hand, see the research support as one of the external fund to be accessed [19] and they jump into any partnership even it might be quite risky. Chang and Hsu studied both managerial and environmental drivers of innovativeness for SMEs to show that internal and external factors are independent [20]. Global collaboration changed the collaborative strategies both in functional operations and collaborative activities [21]. The economic crisis has led research and development for innovation towards a new approach and perspective: innovation through new products/processes or knowledge is not enough beneficial unless the systems around them are not ready. This is a common issue among the developing and highly developed countries [22].

Literature surveys allowed us depict thirty-two innovative synergy factors representing either organizational approach or alliance approach. Previous research also shows that these criteria are mainly analyzed by constructing the clusters in the same geographical region by using the collective intelligence methods [23, 24].

Table 1. Organizational Features Effective in Collaboration Synergy

Factor	Information Resource	Reference
Organizational structure	Organizational Manual & Management Survey	Twardy (2009)[25]
Administrative Capacity		Margoluis (2008)[26]
Values & Company culture	Employee & Management Survey	Rai et al.(1996)[27] Ding (2009)[28]
Reward& compensation systems		
Performance culture		
Financial condition	Company Balance Sheet	Rameshan&Loo(1998)[29] Chen et al(2008)[30] Twardy (2009)[25] Ding (2009)[28]
Organizational resources	Company balance sheet & Management Survey	Margoulis(2008)[26] Rose et.Al. (2010)[31]
Technological Capabilities	Technology Assessment	Chen et. al(2008)[30]
Brand / Firm reputation	Sales Information	Ding (2009)[28]
Visions, Goal & Objectives	Employee & collaborator Survey	Margoluis (2008)[26] Gomes-Casseres (2003) [32]
Company Pace		Linder (2004)[33] Margoulis(2008)[26]
Type of Leadership		

Some of the factors found during the literature survey are very similar and most of them cannot be expressed in figures. Therefore a need to combine or discard the least influential ones is observed. A fuzzy cognitive survey is responded by one SME executive, one academic expert on SMEs and a strategy consultant for SMEs. Fuzzy cognitive analysis allows linking the factors in a positive or a negative relationship with a degree in the interval [-1,1]. The weight given for each criterion is found through the centrality calculated by using the sum of scores given in the column (inbound) of the criterion, and the sum of scores given in the row (outbound) of the criterion in the normalized relations matrix.

Organizational factors like the governmental support or country, and intangible alliance factors like past alliance experience are eliminated since they had weights lower than 1%. Hence the set of factors that will be used in the synergy survey are reduced to 22 criteria, which are shown in Table 1 and Table 2. The survey demonstrated that the highest importance is recorded for the structure of alliance or the clarity of roles with a weight of 6.21. The selected criteria are explored below in the rank of their weights. It is remarkable that the first seven criteria are intangible alliance criteria.

Structure of Alliance (Clarity of Roles): A tangible alliance criterion. Margoluis [26] discusses that for an alliance in order to be effective, individuals and companies should know their tasks in a complete manner.

Inter-organizational trust: Ramaseshan and Loo [29] proves that inter-organizational trust positively affects the alliance. It has also been claimed as one of the most effective criteria for the existence of collaborations [34].

Dysfunctional conflict: Dysfunctional conflict is defined as disputes that cannot be agreed on [29]. Unlike dysfunctional conflict, functional conflicts are disputes that can be agreed on. Ramaseshan and Loo proves that excessive number of dysfunctional conflicts can negatively affect the efficiency of an alliance.

Values and company culture: Twardy [25] denotes that collaborating companies are deemed to face cultural differences during the alliance initiation. Besides, [27] claims that these differences may occur even among the companies within the same country or the same industry. Company culture also includes the decision making mechanism which is analyzed under the Organizational Structure" and Type of leadership" topics". It is also claimed that in alliances different cultures are forced to find a common ground for the sake of alliance.

Communication, coordination and information sharing systems: Communication is defined as the ability to interact and share information in an apparent manner [26] and it is one of the alliance efficiency affecting criteria according to Ding [28].

Commitment capabilities to alliances: Ramaseshan and Loo [29] proves that as openness and commitment of companies increase, the efficiency of the alliance increases. It has been found to decrease the turnover rate and increase the lifetime and the accordance of an alliance.

Inter-organizational communication: Inter-organizational communication is defined as formal as well as informal sharing of meaningful information between firms" [29]. In alliances, it is possible that both human and the machine problems may arise.

Scope of the alliance: Eden [34] discusses that a restricted scope negatively affects the efficiency of the alliance. It is recorded that more effort is spent on resolving the conflicting scope ideas among the firms.

Funding Balance: Linder et. al. [33] and Twardy [25] state that expectations from the alliance have a big impact on the health of alliance. The decision of the funding regime should be clarified before the constitution of the alliance and firms should not avoid to contribute.

Attitude towards alliance: Attitude towards alliance denotes whether the company is willing and ready for alliance [32]. As the eagerness of the company increases, the probability of synergy increases.

Table 2. Alliance Features Effective in Collaboration Synergy

Factor	Information Resource	Reference
Scope of Alliance	Contract, Employee Survey	Eden (2007)[34] Margoluis(2008)[26]
Structure of the alliance (clarity of roles)		Margoluis(2008)[26]
Compatibility of vision/goals&objectives		Gomes-Casseres (2003) [32]
Funding balance		Linder et. al.(2004)[33]
Attitude towards alliance	Employee & Project Manager Interviews	Linder et. al.(2004)[33] Rai et. Al.(1996)[27]
Inter-organizational communication		Margoluis(2008)[26]
Commitment capabilities to alliances		Eden(2007)[34]
Communication, Coordination& information sharing	Management Survey	Chen et al(2008)[30] Twardy (2009)[25] Ding[28]
Dysfunctional conflicts		Rameshan&Loo(1998)[29]
Inter-organizational trust		Gardet & Mothe, (2012)[35]

Compatibility of vision, goals and objectives: The vision, goals and objectives of collaborating companies are expected to be compatible as well as clear [31]. Conflicting or irrelevant objectives may decrease the lifetime of alliances as in the scope criterion.

Organizational Resources: Organizational resources given to the service of the collaboration are listed as skilled personnel, trade contacts, machinery, efficient procedures and capital [31]. Most of the researchers state that allies are to be complementary in covering the resource needs. Since the amount of contribution differs by company, this property is considered as organizational property.

Organizational Structure: Twardy [25] states that the governance model of a company has more than 25% importance on the success of an alliance. The best condition for synergy is to balance the freedom and control in a collaboration.

Company Pace: Company pace denotes whether the collaborating company is able to adapt changes in a slow or fast manner [32]. It is possible to assign benchmark points for this criterion such as industry average, rivals or business partners.

Administrative capacity: Administrative capacity is defined as the capacity of the organization to manage grants, reporting procedures and administrative tasks" [26]. It is defined by the self-evaluation of the company in the following four areas: Management, Programming, Monitoring, Evaluation.

Brand, firm reputation: According to Ding [28], having a good reputation in the target geographical scope is one of the most important criteria in alliances. A good reputation may increase the eagerness to collaborate.

Financial condition: Financial condition is revealed as a very important factor in alliances discussed in various number of studies [25][28,29,30]. It can be summarized as the more the financial power of companies is, and the better the financial condition of the collaboration is, the synergy is improved".

Type of leadership: Leadership style heavily influences the decision making structure of an organization [26]. Type of leadership is not included in the organizational structure since the first indicates the implementation of decisions whereas the latter shows the participation in decisions.

Performance culture: Performance culture is the approach for measuring the success of the employees and the company regularly, in a planned and methodic way or just ad-hoc and intuitive. Cheung [36] implies that project performance measure culture has an effect on alliance debates. It is also recorded that integrating very different performance measure cultures is an issue, whereas if cultures are similar, it is more manageable to integrate.

Reward and compensation system: Rai et. al. [27] implies that applications in human resources, especially reward and compensation systems, have a big impact on the working capacity of collaborations. Moreover, he argues that difference in such systems may arise even in the same countries or industries. Different types of compensations may include base pay, commission, overtime pay, bonuses, profit sharing, stock options, ravel / meal / housing and other benefits such as dental, insurance, medical, vacation, leaves, retirement, taxes. Though it is an organizational feature the accordance of these properties increases the strength of alliance.

Technological Capacities : Chen et. al. [30] state that technological capabilities of companies within alliance should be complementary. Yet, they do not provide a list of technological resources to be met. Data gathered from the literature provide various resources for different industries. In this study we provide basic elements that are valid for all industries covering computer hardware, system integration and management tools, communication equipment and software, automated data processing, database management systems, management information systems, knowledge base and infrastructure.

Clarity of visions, goals and objectives: Margoluis [26] states that visions, goals and objectives should be common or at least shared between the partners. Besides, in order to share a vision, a goal or an objective, they must be clear and well understood by the collaboration team members [32].

All studies apart from Huang et al. [10] ignore the synergy phenomenon in their studies. The concept is integrated in all objectives of collaboration as a coefficient.

The above mentioned criteria are thoroughly analyzed in the model building and application phases. It is observed in literature that generally used methods to select partners can be summarized as follows:

- The statistical methods are used to measure the efficiency of existing collaborations. The methods are static, and do not consider the new collaborations that can emerge.
- Multi criteria decision methods are used to maximize the innovation power or determine the reasons for the risk without considering the exponential effect of the synergy.
- Mathematical methods are used to model non-linear effects with possible 2n-1 collaboration link for n companies causing computational difficulties.
- Meta-heuristic algorithms are generally used to model the multiple objectives with simpler mathematical models.

It is also observed that none of these methods are used for clustering approach.

3 Synergy Index

3.1 Synergy Index Formulation

Synergy is defined as the gratifying factor for the combined performances of the individual companies [35]. The better is the accordance within the alliance, the greater is the synergy. Hence, synergy is positively related with the accordance. In other words, the system that makes the alliance work has to be robust for a lifetime of an alliance. Reliability can be defined in good working synergy criteria when the expected life of collaboration is the concern. The expected lifetime of alliance can be calculated using Weibull distribution which is accepted as the best function of lifetime calculation in the reliability theory [37, 38]. Weibull distribution has the following features:

Density function :

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-v}{\alpha}\right)^{\beta-1} \exp\left\{-\left(\frac{x-v}{\alpha}\right)^{\beta}\right\} \tag{1}$$

Cumulative function:

$$F(x) = 1 - \exp\left\{-\left(\frac{x-v}{\alpha}\right)^{\beta}\right\} \tag{2}$$

Where $x > v$ and α, β and v are Weibull parameters.

Expected value:

$$E[X] = \alpha.\Gamma(1 + \frac{1}{\beta}) \tag{3}$$

The analogy between the synergy and the lifetime suggests $v \geq 0$, since we take the two, analogous $v = 0$ will be accepted. In the formula β is the shape parameter and α is the rate parameter. For one company case, $\beta = 1$, the distribution becomes the Exponential distribution. For $\beta = 2$, the distribution becomes the Weibull distribution but for $\beta > 5$ it is not any more the same distribution.

Hence, distribution of synergy is modeled as the reliability of a system of n where $1 \leq n \leq 5$ components. Therefore, it is safe to accept β as the number of companies in the collaboration cluster. In physical and biological systems, synergy is modeled with an accelerating effect, which resembles the shape of exponential distribution [38]. This allows us take the shape parameter β to denote the *number of firms in collaboration*. It is also viable to emphasize that the collaboration of more than 5 companies are not practical in the business life. Though there are examples of more than 5 companies in European projects, two features of these teams are to be recognized: they are not all SMEs (sometimes a big company like SAP or IBM takes place in the team) and the team is built only for one project.

Weibull distribution will be constructed for each company considering the synergy coefficients and the number of companies in collaboration as parameters. Inter-company synergy will assume to have $1 \leq n \leq 5$ firm(s) in alliance.

The parameter α resembles the strength of elements in the reliability analogy, which is equivalent to the *merged synergy coefficient* that will be calculated using synergy factors. The synergy index $\mathfrak{s}$ can be defined as

$$\mathfrak{s} = \alpha.\Gamma(1+\frac{1}{\beta}) \tag{4}$$

α: the merged synergy coefficient
β: number of companies

The synergy index will be used in calculating the maximization of innovation power. It is known that in collaborations the innovation can be greater than the sum of the individual if the accordance is well established. Hence, we try to maximize the minimum synergy among the collaborating companies. Each collaborating group is important and the company left outside the group must be successful if included in collaboration.

It should also be clear for the collaborating companies that if the synergy factors are merged in a negative way, that is, if the companies are discordant, the synergy index will be negative showing no possible lifetime for collaboration clusters.

3.2 Sensitivity Analysis

The proposed synergy index is sensitive to the number of firms in alliance. As an example, there exists 2 collaboration clusters, one with 2 companies and the second with 3 companies. In case the merged synergy coefficient α=0.7 for both clusters, 3-company-alliance gives a better $\mathfrak{s}$ than the 2-company alliance. This can be considered as a parallel system. It is always safer to increase the number of parallel elements. In Figure 1, synergy index sensitivity of number of firms in alliance for $\alpha = 0.7$ is demonstrated.

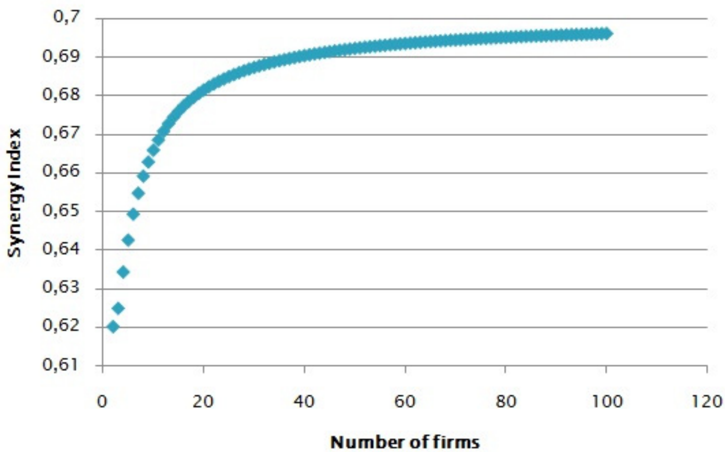

Fig. 1. Synergy index sensitivity for the number of firms

Synergy effect in innovation is shown to support the moral as well as causing improvements in project follow-up, creativity and technological intelligence when thresholds are taken into account [39]. The previous evaluations of synergy were mainly based on scoring because of the intangible factors.

4 Foraging Search

4.1 Motivation

The Foraging Search algorithm imitates the Animal Food Chain for optimization problems [40]. Animal Food Chain contains three groups: herbivores (plant eaters), omnivores (both plant and meat eaters) and carnivores (meat eaters). Herbivores are known as primary consumers, omnivores who feed on some specific plants and other herbivores are known as secondary consumers and lastly, carnivores who feed on specific herbivores and carnivores are known as the tertiary consumers. Herbivores are ultimate hunts of the food chain whereas carnivores are the ultimate hunters and omnivores, which are both hunters and hunts. According to the energy transformation, the energy transmitted through a food chain decreases as the number of consumers increase. The ratio of hunt and hunters depend on the ecological environment. In wild environments, the herbivore-omnivore-carnivore ratio can be 10:3:1 whereas in calm environments the related ratio can be 40:10:1. Additionally, it is also valid that in a food chain, the hunter is always faster than the hunt [41, 42].

The classical PSO algorithm employs one swarm and the related swarm is responsible for both exploration and exploitation[43].There is a new algorithm that implements two swarms of equal sizes clustering [44] separating the responsibilities for exploration and exploitation.

The Foraging Search uses three swarms, namely herbivores, omnivores and carnivores, to provide exploration by the herbivore swarm, exploitation by the carnivore swarm and exploration-exploitation balance by the omnivore swarm. Introduction of a food chain provides an incremental escaping ability which is modeled with first level and second level hunters. All fear and escape factors affect the speed of the animals, which the Foraging Search model embeds in the velocity update formula. Furthermore, this algorithm considers the environmental wildness which represents the complexity of the market. If the competition is harsh it is better to increase the wildness. That is why Foraging Search balances the exploration and exploitation at the swarm level.

4.2 The Clustering Algorithm

Each particle in the Foraging Search Clustering algorithm is represented by $k*d$ cluster centers where k is the number of clusters and d is the number of dimensions of the data points to be clustered. Likely, the velocity and speed updates are applied in order to locate optimum cluster centers.

Thirteen steps are followed:

Step 1. The environment is defined as calm, regular or wild.
Step 2. The herbivore : omnivore : carnivore (*h_number:o_number:c_number*) ratio is determined.

- IF the environment is harsh: wild 10:3:1
- IF the environment is average: 25:6:1
- IF the environment is calm: 40:10:1

Step 3. Each particle is randomly initiated for each swarm, each particle is assigned random$c*d$ cluster centers where c is the number of clusters and d is the dimension of data points. The particles are named asx_{ijk}, the k^{th} dimension of thej^{th} cluster of the i^{th} particle where i= 1, ... $h\_number \vee o\_number \vee c\_number$, j = 1, ..., c, k = 1, ..., d.

Step 4. Data points are assigned to clusters using a distance metric (e.g. Euclidean distance, Mahalanobis distance, etc...).

Step 5. The quality of the clustering is measured by an objective function. The aim of clustering is building small clusters as dissimilar as possible. Consequently, the objective function may involve within cluster distances, among cluster distances or a combination of both measures.

Step 6. The best objective value and position for all particles, or particle bests, are determined for each particle in each swarm.

Step 7. The best objective value and position, or swarm bests are determined for each swarm.

Step 8. The best objective value and position of all swarms, or the global best is determined.

Step 9. The fear coefficients for herbivores are calculated.
Fear factors for herbivores:

$$pfho_i = 1 - \frac{d_{fho,i}}{d_{fho}^{\min}} \tag{5}$$

$$pfoc_i = 1 - \frac{d_{foc,i}}{d_{foc}^{\min}} \tag{6}$$

where
i= 1,…,h_number

$pfho_i$: fear degree from omnivores of the i^{th} herbivore (in the interval [0,1])
$pfhc_i$: fear degree from carnivores of the i^{th} herbivore (in the interval [0,1])
$d_{fho,i}$: the distance of the i^{th} herbivore to the nearest omnivore
$d_{fhc,i}$: the distance of the i^{th} herbivore to the nearest carnivore
d^{min}_{fho}: the minimum distance for a herbivore to fear an omnivore
d^{min}_{fhc}: the minimum distance for a herbivore to fear an omnivore

Step 10. The fear coefficients for omnivores are calculated using the formula below:

$$pfoc_i = 1 - \frac{d_{foc,i}}{d_{foc}^{\min}} \tag{7}$$

where
i= 1,…,*o_number*
$pfoc_i$: fear degree from carnivores of the i^{th} omnivore (in the interval [0,1])
$d_{fho,i}$: the distance of the i^{th} omnivore to the nearest carnivore
$d^{min}{}_{fhc}$: the minimum distance for an omnivore fear an omnivore

Step 11. The probability of being a hunt for omnivores is calculated as

$$pp_i = \frac{dc_i}{dc_i + dh_i} \tag{8}$$

where
i = 1, …,*o_number*
pp_i: : the probability of omnivores being a hunter
dh_i: the distance of i^{th} omnivore to the nearest herbivore
dc_i: the distance of i^{th} omnivore to the nearest carnivore

Step 12. The velocities (v_{ijk}) of each particle are updated according to their swarms.

a. *Velocity Update for the Herbivore Swarm*

Since herbivores are ultimate hunt, their velocity update involves the escape from their first and second level hunters: omnivores and carnivores. The velocity update formula for herbivores is given below.

$$v_{ijk} \leftarrow wv_{ijk} + c_1 r_{1i}(y_{ijk} - x_{ijk}) + c_2 r_{2i}(\hat{y}_{ijk} - x_{ijk}) + pfho_i c_3 r_{3i} D(d_{fho,ijk}) + pfhc_i, c_4 r_{4i} D(d_{fhc,ijk}) \tag{9}$$

where
i= 1,…., *h_number*
v_{ijk}: the velocity of k^{th} dimension of the j^{th} cluster of the i^{th} particle of the swarm
w: the inertia coefficient
$c_1$and c_2: cognitive and social coefficients
r_{1i}, r_{2i}, $r_{3i}$and r_{4i}: random numbers for the i^{th} particle in the interval [0,1]
y_{ijk}: personal best for the k^{th} dimension of the j^{th} cluster of the i^{th} particle of the swarm
x_{ijk}: the position of k^{th} dimension of the j^{th} cluster of the i^{th} particle of the swarm
$\hat{y}_{jjk}$: swarm best for the k^{th} dimension of the j^{th} cluster of the i^{th} particle of the swarm
c_3: distance based coefficient of herbivores from omnivores
c_4: distance based coefficient of herbivores from carnivores
and

$D(.)$ is a measure of the effect that the hunter has on the hunt and it is formulated as

$$D(x) = \alpha e^{-\beta x} \tag{10}$$

where d is the Euclidean distance between the prey particle and the nearest hunter particle. α and β are positive constants that define the effect of distance to velocity.

b. *Velocity Update for the Carnivore Swarm*
Since herbivores are ultimate hunt, their velocity update involves independently chasing the nearest hunt. The velocity update formula for herbivores is given below.

$$v_{ijk} \leftarrow \left(\hat{y}_{ijk} - x_{ijk}\right) \tag{11}$$

where
$i = 1,\ldots, c\_number$
v_{ijk}: the velocity of k^{th} dimension of the j^{th} cluster center of the i^{th} particle of swarm
r: random number in the interval [0,1]
$\hat{y}_{ijk}$: the position of the k^{th} dimension of the j^{th} cluster center of the nearest hunt to the i^{th} particle of swarm
x_{ijk}: the position of the dimension of the j^{th} cluster center of the i^{th} particle of swarm

c. *Velocity Update for the Omnivore Swarm*
Since omnivores are both hunters and hunts, their velocity update involves the compound of both velocity update formulas whose ratio depend on the probability of being a hunter. The velocity update formula for herbivores is given below.

$$v_{ijk} = (1 - pp_{\text{i}})\left(wv_{ijk} + c_1 r_{1i}\left(y_{ijk} - x_{ijk}\right) + c_2 r_{21}\left(\hat{y}_{ijk} - x_{ijk}\right) + pfoc_i c_3 r_{3i} D\left(f_{foc,ijk}\right)\right) + pp_i\left(r\left(\tilde{y}_{ijk} - x_{ijk}\right)\right) \tag{12}$$

where
i= 1,….,h_number
v_{ijk}: the velocity of k^{th} dimensionof the j^{th} cluster of the i^{th} particle of theswarm
w: the inertia coefficient
$c_1$and c_2: cognitive and social coefficients
r_{1i}, $r_{2i,}$ r: random numbers for the i^{th} particle in the interval [0,1]
y_{ijk}: personal best for thek^{th} dimensionof the j^{th} cluster of the i^{th} particle of the swarm
x_{ijk}: the position of k^{th} dimensionof the j^{th} cluster of the i^{th} particle of theswarm
$\hat{y}_{jjk}$: swarm best for thek^{th} dimensionof the j^{th} cluster of the i^{th} particle of the swarm
$\tilde{y}_{ijk}$: the position ofthek^{th} dimension of the j^{th} cluster center of the nearest hunt to the i^{th} particle of swarm
c_3: distance based coefficient of herbivores from omnivores
c_4: distance based coefficient of herbivores from carnivores
and

$D(.)$ is a measure of the effect that the hunter has on the hunt and it is formulated as

$$D(x) = \alpha e^{-\beta x} \tag{13}$$

where d is the Euclidean distance between the prey particle and the nearest hunter particle. α and β are positive constants that define the effect of distance to velocity.

Step 13. The particle positions for each particle in each swarm are updated using the formula below:

$$x_{ijk} = x_{ijk} + v_{ijk} \tag{14}$$

where
x_{ijk} : the position of k^{th} dimension of the j^{th} cluster of the i^{th} particle of theswarm
v_{ijk}: the velocity of k^{th} dimension of the j^{th} cluster of the i^{th} particle of theswarm

5 Case Study

The synergy index is studied for a case of 51 SME companies in Thrace, Turkey. The companies are distributed in several industries as shown in Table 3.

Table 3. Industrial distribution companies in the case study

Industry	%	Industry	%
Food	17.6	Service	15.7
Clothing & Textile	13.7	Health	5.7
Machinery & Electronics	19.6	IT & Communication	7.8
Automotive	2.0	Construction	2.0
Chemical & Pharmaceutical	0.0	Furniture	2.0
Plastics	2.0	Metal	2.0
Publishing	2.0	Miscellaneous	7.9

A survey of 22 questions is run for 51 companies to figure out the approaches on 22 synergy factors. In order to measure the intangible alliance criteria, linguistic variables are presented in scenarios that would reflect the SME opinion. For example, since the firms do not know each other, they cannot be asked how much each trusts the others. Instead, it can be asked about how much they trust the alliance and how much they are willing or open to share as in the linguistic options that can be evaluated by the responder:

- We want to participate in collaborations but we do not have the experience
- We can contribute to alliances but our resources are limited.
- We are ready for collaborations that do not interrupt our daily processes.

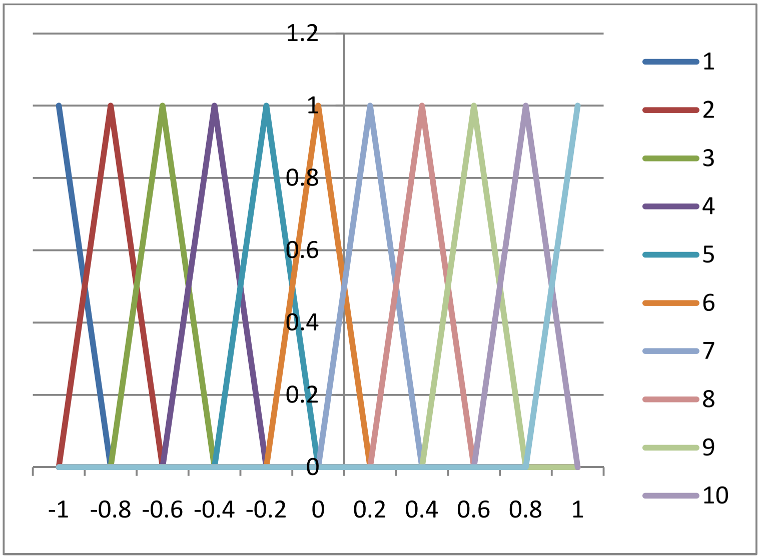

Fig. 2. Fuzzy numbers for 11-point likert scale

The questionnaire is constructed to score all twenty-two criteria with the above linguistic approach after receiving responses for more statistical information like how many white collar employees work for the company; would the size of the company be considered medium, small or micro or how many patents they have. Questions included different ranges of likert scales in order to represent the synergy criterion clearly. The scales of 5, 7 or 11 values are given in to present the choice between the two ends depending on the possibility of responses. The three samples given below represent different types of questions.

In order to ask for the attitude towards alliance the question is:

- *How does your company consider research collaboration?*

Ignored		Indifferent		Enthusiastic
1	2	3	4	5

The second sample represents the funding balance criteria:

- *How would your company prefer funding the research investments in collaboration?*

Partners with highest funds pay the highest percentage					Some should pay the short term and the others longterm investments					Each company pays his part and the common parts are defined in the contract
1	2	3	4	5	6	7	8	9	10	11

The third sample question asks about the vision, goal and objectives

- *Score validity of the following statements for your company*

	Not valid			Doubtful			Fully Valid
Written mission, goal and objectives are fully implemented and owned by the employees.	1			4			7
Written mission, goal and objectives are implemented but not owned by the majority of employees.	1			4			7
We have written the mission, goals and objectives but they are modified continuously and not owned by the employees.	1			4			7

Responses are clustered using the Foraging Search Algorithm and the synergy is calculated in clusters. Since the analogy of reliability is used for the synergy index, SMEs within a cluster act as a series system, that is, if one SME fails the collaboration has to be reconstructed in order to make it work. On the other hand, all clusters work independent of each other.

The case of no collaboration where none of the firms collaborate with each other, can be considered as a collaboration clusters where one firm exists in each cluster, which gives a synergy index of 0. Hence, the effect of synergy becomes $e^0 = 1$ for each firm, which means the strength of each firm equals to its own strength. It is plausible that for any innovation or other types of collaborations to be favorable, synergy in the cluster should be equal to or greater than 1, since the aim of the collaboration is creating positive synergy among partners. When the cumulative becomes -1 then there is negative energy, the power after collaboration is less than the company power alone.

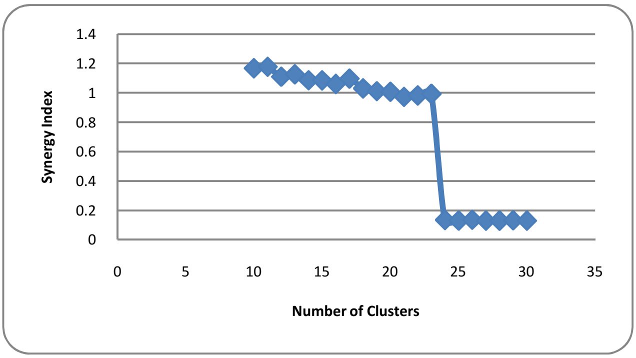

Fig. 3. Synergy Index Achieved based on Number of Clusters

When 2 clusters were run to have 29 and 24 companies each, it is observed that maximum synergy was created between SME 1 and SME 2. It was too crowded to be realistic in the business life. On the other hand, when beta constraint is restricted to be less than equal to 5 each cluster has 5 companies in 10 clusters as seen in Figure 3. In order to see the less crowded situations 11-30 clusters are also run. The best result is achieved by 11 clusters case with a synergy index scoring 1.18, meaning the life of collaboration is extended by 18%. The fact that repeated runs for each number of clusters gave the same exact results makes us believe this is the global optimum.

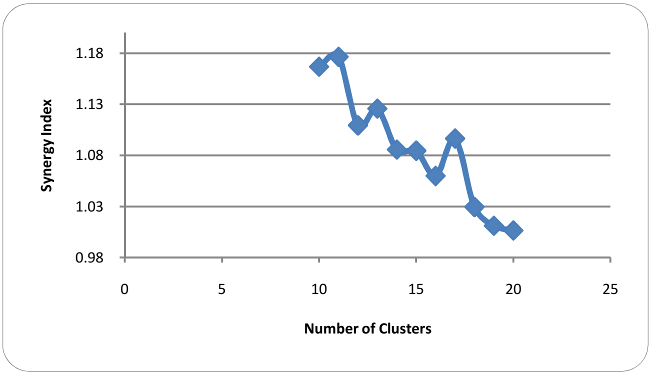

Fig. 4. Synergy Index change detailed for 10-20 Clusters

As detailed in Figure 4, the best objective value obtained is 1.18 with 11 clusters each having number of companies {5},{5},{5},{5},{4},{4},{5},{3},{5},{5} and {5}. Minimum synergy effect is obtained to improve 3% in 18 clusters. This means the life of collaboration is prolonged from 1 year to 1.03 years. The eleventh cluster only includes SME 2 as one of the most synergetic companies. Cluster 11 owns five companies from different industries in variety of sizes as shown in Table 4.

The correlation among the companies is found small enough to be ignored.

Table 4. Content of the most successful cluster

SME No	Industry	Size
2	Electronics	Micro
4	Security Service	Micro
8	Textile	Micro
27	Steel Production	Medium
40	Auto-Spare Part Service	Small

It is observed that the successful collaboration is foreseen among companies from the most classical industries like textile and steel production and most technological industries like electronics and security service. Table 4 also shows that micro, small and medium companies can work together. The correlation among the synergy criteria achieved by the companies in the cluster 11 is measured. The *t* test applied with 10 % significance showed that the correlation is too small to be ignored.

Therefore we can conclude for our case application with the following summary: unlike a generalized belief of industry and technology focus in collaboration, synergy is not only based on industry. All twenty-two criteria are evaluated by the respondent companies and the most critical influencers are evaluated as alliance approaches and balance of the resources. It is also observed that the micro companies give more importance to the human resource based criteria, whereas the medium size companies which have more opportunity for investment see issues on the collaboration critic factors.

It is experienced in business that the collaboration is more difficult as the number of partners increase. That is why this case is an initial study on measuring the collaborative innovation by using clustering method. The approach should be extended by relating the synergy effects on innovation power, innovation risks and financial changes. Only then we can propose SME s to collaborate with 3-4 more SMEof different size in different industries.

6 Conclusion and Suggestions

Innovative synergy is requested for collaborative research and development that is an obligatory process for the small and medium companies. This study proposes a synergy index that will help the SMEs to decide which companies will maximize the synergy if collaborated. The synergy is accepted as the life of collaboration which will be prolonged with robust partnerships.

The novelty of the paper is proposing a new approach to measure synergy for collaboration which is constructed and achieved by using a very new collective intelligence method, Foraging Search. Both the approach and the method have not been used before. The construction of survey on the intangible criteria is based on linguistic approach and therefore evaluated by using fuzzy measures. The number of companies in collaboration is restricted to 5 in order to avoid risks involved in increasing number of partners.

A case study is run for the 51 SMEs in Thrace, Turkey showed that the synergy is maximized when number of clusters is increased to 11, the best synergy is obtained with a group of five companies as 1.18, meaning that the life of collaboration will be increased by 18%. It is observed that the innovation is received with companies of different sizes and from a variety of industries. The business and alliance approaches of companies have a bigger role in synergy. This conclusion suggests that SMEs are to be trained to collaborate with the companies that strengthen their weak points.

The proposed approach is to be further developed by validity analysis through comparisons with different approaches and different methods. Further studies are developed to measure synergy in effect of economic development, innovation power maximization, and or minimizing the innovation risks. It is also suggested that the synergy calculation is to be validated for different countries and international collaborations. A further study on synergy will also be run to measure the strength of SME collaboration synergy in the supply chain of power games.

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