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Intelligent assignment in clusters to enhance collaboration and innovation

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Abstract

Purpose – Small organizations within profit maximization supply chains form industrial clusters to share resources. They mainly deliver products and services in a reactive manner, where the cluster is only facilitating. However, the cluster management can lead business development and assign work packages intelligently to appropriate cluster members by respecting collaboration and innovation. This upgrade of the cluster management requires a systematic approach. Therefore, the intelligent Cluster Assignment Tool concept is developed and an illustrative example is given. The paper aims to discuss these issues.
Design/methodology/approach – Interviews and workshops were used to isolate the hierarchy of the assignment model, supported by a literature research. Fuzzy analytic hierarchy process method was applied to determine weights, consolidating data delivered by members of a Turkish aviation and defence cluster. The approach was discussed at the IEEE 2016 ICE Conference in Norway with experts to assess regional restrictions.
Findings – Cluster members are actively looking for possibilities to enhance innovation potential that they are ready to participate in systematic approaches. Cluster organizations can differ by leading their members actively, when respecting all isolated dimensions of assignment. This can lead towards a cooperation base enhancing the potential for innovation and new product development (NPD).
Research limitations/implications – The illustrative example indicates a good fit to clusters without a dominant anchor firm. The generic framework was deliberated on cross-sectional perspective as satisfactory to be applied to different sectors in developing economies.
Practical implications – This paper helps clusters and small organizations to upgrade for innovation. Furthermore, it delivers a strategic tool supporting organizational transformation, preventing the price trap as well.
Originality/value – This approach is focussing on multi-criteria assignment across cluster members, upgrading it to a united organization. It delivers a strategic framework for cluster management, building a collaboration environment leading to innovation and NPD.

Keywords Innovation, Fuzzy logic, New product development, Analytical hierarchy process (AHP), Supply networks, Virtual organizations

Paper type Conceptual paper

1. Introduction

Large enterprises reduce input costs through global sourcing by allocating best available suppliers (Yücenur *et al.*, 2011). Therefore the supply chain is integrated as an economizing strategy (Ursino, 2015), interacting linearly upstream or downstream to produce value in the form of products and services (Yusuf *et al.*, 2014). Such supply chains are driven by profit maximizing processes, preventing mutual knowledge generation, which is a prerequisite of innovation (Casanueva *et al.*, 2013). However, competitive firms have to be innovative and thus upgraded by increasing their skill content to move into new market niches (Humphrey and Schmitz, 2002). Consequently organizations within geographical proximity form clusters, which are supporting competitiveness (Porter, 1998; Karaev *et al.*, 2007), information exchange (Casanueva *et al.*, 2013; Garetti and Taisch, 2012) and thus an enhanced form of collaboration (Porter, 1998).

The main advantages of clusters are associational cognition, learning, increased variation, and deepened division of labour (Pitelis, 2012). Since joint allocation of resources involves all participants' collaboration, the shared knowledge across the cluster grows

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(Lima and Carpinetti, 2011) and this strengthens the cluster further (Gerolamo *et al.*, 2008). Lowering the costs by shared resources, clusters can motivate improvement more productively (Porter, 1998) and deliver a higher business performance (Li and Geng, 2012).

Increased efficiency and productivity in clusters result in regional growth (Garanti and Zvirbule-Berzina, 2013). As a result there is a strong policy interest in developing countries (Li and Geng, 2012) to include small and medium enterprises (SMEs) in clusters (Karaev *et al.*, 2007; Kunt *et al.*, 2012), where the exchange of tacit knowledge across the cluster can lead to innovation (Casanueva *et al.*, 2013) and enhance the innovation performance (Lai *et al.*, 2014). Consequently clusters are one of the most favoured forms of competitiveness policy worldwide (Pitelis, 2012).

The problem is that cluster members do promote competition and cooperation (Porter, 1998). Consequently they might pursue their interests without resorting to full integration (Pitelis, 2012). Especially when the cluster is not mature, aggressive pricing policies of members might result in unprofitable businesses, endangering the cluster's existence. Thus the establishment of an appropriability-informed agency is required to prevent zero profit condition (Pitelis, 2012). When there is a cooperation-based information system (Bhagwat and Sharma, 2007), the cluster management (CM) can involve in the assurance of a sustainable, competitive positioning (Kunt *et al.*, 2012).

Who shall be the owner of such a system? Since cluster managers are already upgraded, they did grow over a facilitator (Ingstrup and Damgaard, 2013) to an organizer, coordinator, developer, promoter and integrator (Carpinetti and Lima, 2013; Ingstrup, 2013). Thereof business development is carried out by the CM, and new cross-organizational projects might be an outcome (SAHA, 2015). The CM can then differentiate the cluster through this leading position by assigning work packages in such projects intelligently to appropriate cluster members with respect to their collaboration and innovation potential. To isolate the constitutional basics of such a system, first the supply chain literature with respect to selection is looked on, then a model called the intelligent Cluster Assignment Tool (iCAT) is synthesized based on the literature, interviews and workshops, and finally the iCAT concept is illustrated with an example.

2. Literature review

All in one it is a multi-criteria decision making (MCDM) problem. Furthermore, iCAT has to cover typical requirements of procurement processes. Consequently focus was on the literature for MCDM with respect to supplier selection. MCDM involves mutual compromise for multiple objectives or attributes, and the main methods are weighted sum method, weighted product method, analytical hierarchy process (AHP), preference ranking organization method for enrichment evaluation (PROMETHEE), the elimination and choice translating reality (ELECTRE), the technique for order preference by similarity to ideal solutions, compromise programming, multi-attribute utility theory, or a combination of these methods (Pohekar and Ramachandran, 2004). AHP is used in selection and evaluation (Ishizaka and Labib, 2011) as the most frequently applied MCDM technique, followed by outranking techniques PROMETHEE (Araz and Ozkarahan, 2007) and ELECTRE (Pohekar and Ramachandran, 2004). There can be significant divergences due to subjective weights in ELECTRE (Salomon and Montevechi, 2001) or PROMETHEE that AHP extensions with pairwise comparisons are incorporated (Araz and Ozkarahan, 2007). AHP is in fact supporting the natural tendency of the human mind (Huang and Keskar, 2007), where only verbal statements for pairwise comparisons have to be made instead of point estimates (De Boer *et al.*, 2001). Moreover the aim here is not to outrank the supplier as in ELECTRA (Sevkli, 2010), but to build a structured lean decision environment based on a hierarchy, which can yield a system architecture. As a result, AHP was selected in the first line as the MCDM method for iCAT, and in later section it is explained in detail.

The AHP

AHP (Saaty, 1980, 1990) is a flexible, standardised method, converting a complex problem into a simple hierarchy (Pohekar and Ramachandran, 2004), and it is widely applied in the supply chain (Narasimhan, 1983; Nydick and Hill, 1992; Mohanty and Deshmukh, 1993; Petroni and Braglia, 2000; Kahraman *et al.*, 2004; Arshinder *et al.*, 2007). Products, as well services such as outsourcing (Kahraman *et al.*, 2010) and logistics (Kannan, 2009) are within the scope of AHP.

AHP arranges factors from the goal descending to successive levels, respecting their militating potential in the decision (Saaty, 1990). This decomposition delivers clear and understandable pieces of information within a hierarchy, where pairwise comparisons of the criteria are done using several scales (Ishizaka and Labib, 2011). The pairwise comparisons are stored in a square and positive reciprocal ($n \times n$) matrix (Shiraishi *et al.*, 1998) as:

$$A = \begin{pmatrix} a_{11} & \dots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \dots & a_{nn} \end{pmatrix} \text{with} \begin{cases} a_{xy} = 1/a_{yx} \text{ for } x = 1, 2, \dots, n \wedge y = 1, 2, \dots, n \\ a_{xy} = 1 \text{ for } x = y = 1, 2, \dots, n \\ a_{xy} \in \left(\frac{1}{9}, \frac{1}{7}, \frac{1}{5}, \frac{1}{3}, 1, 3, 5, 7, 9\right) \text{for all } x, y \end{cases}$$

The normalized eigenvector $\vec{w}$ of the comparison matrix A respects $A\vec{w} = \lambda\vec{w}$ with λ as the maximum eigenvalue, i.e. the principal eigenvalue (Saaty, 1990, 2003). A must be near consistent and reciprocal, where a_{ij} values for $i, j \in [1; n]$ are reflecting expert opinions with errors in the judgement. Thus A may not satisfy the consistency perfectly with $\lambda_{\max} \geqslant n$ (Shiraishi *et al.*, 1998), but it still may be reciprocal and acceptable. Therefore the consistency ratio (CR) is determined as consistency index (CI) over random CI (RI). When CR is below 0.1 the matrix is accepted as consistent (Forman, 1990; Saaty, 1990):

$$\text{CR} = \frac{\text{CI}}{\text{RI}} < 0.1 \text{ with CI} = \frac{(\lambda_{\max} - n)}{(n-1)}$$

Alonso and Lamata (2006) gave a summary of RI values and defined alternatively the following formula to check the consistency:

$$\lambda_{\text{maks}} \leqslant n + \alpha(1.7699n - 4.3513) \text{with } \alpha\text{: level of consistency needed}$$

When there is a high inconsistency, selected comparisons can be re-evaluated (Saaty, 2003). Given a nearly consistent A, the normalized eigenvector $\vec{w}$ defines weights of criteria. The hierarchical decomposition into several levels enables the combination of several AHP weights consolidating in the global prioritization vector $\vec{R}$. Then, individual evaluations of alternatives are stored in the evaluation matrix E, which multiplication with $\vec{R}$ gives the scores $\overrightarrow{SCR}$ for the selection. In order to integrate later other numerical entities such as cost, the elements of $\overrightarrow{SCR}$ can be divided by the normalized cost $\vec{c}$ in order to include the price impact on the decision as well.

The fuzzification of AHP

AHP involves crisp comparisons, but the real world is complex and incorporates uncertainty, which can be reflected with fuzzy AHP (Laarhoven and Pedrycz, 1983; Ayag and Ozdemir, 2006; Bozbura *et al.*, 2007; Labib, 2011; Yan *et al.*, 2012). Fuzzy AHP can manage the subjectivity in the supplier selection (Bayrak *et al.*, 2007; Ordoobadi, 2009; Kuo *et al.*, 2010), where risk factors (Chan and Kumar, 2007) or information-sharing decisions can be considered (Percin, 2008). Moreover, it can be applied in production planning (Weck *et al.*, 1997), manufacturing information systems, machine selection (Bozdag *et al.*, 2003, Ayag and Ozdemir, 2006), evaluation of organizational performance (Tsai *et al.*, 2010), new product development (NPD) (Ayag, 2005), and determination of the criteria for partner selection (Lee *et al.*, 2011), which are tasks to be fulfilled within iCAT. Consequently, fuzzy AHP was applied in iCAT.

Fuzzy AHP incorporates the usage of trapezoidal (Weck *et al.*, 1997) or triangular (Bozbura *et al.*, 2007) fuzzy sets. Main mathematical operations of these fuzzy numbers are given in Gani and Assarudeen (2012), and detailed fuzzy operations in AHP are outlined by Chang (1996), Ayag and Ozdemir (2006) and Chou *et al.* (2013) for further reading. The first step of fuzzy AHP is to express the linguistic comparisons by using a triangular fuzzy scale as explained in Bozbura *et al.* (2007). Then, all described AHP operations are made with these fuzzy numbers. Fuzzy extent analysis was used to reduce the computational requirements (Chang, 1996; Buyukozkan *et al.*, 2004; Bozbura *et al.*, 2007; Yücenur *et al.*, 2011), where fuzzy synthetic extent of all criteria and alternatives are calculated by replacing the fuzzy arithmetic mean with the fuzzy geometric mean (Chou *et al.*, 2013). However, it was proven that this method is incorrect and it does not make full use of all available information (Yan *et al.*, 2012). Moreover it may assign an irrational zero weight that the relative importance might not be represented, leading to wrong decisions (Wang *et al.*, 2008). Consequently a full fuzzy operation was adopted here, simply applying AHP with fuzzy numbers instead of crisp numbers.

3. Data and proposed method

This study originated from the need to enhance the innovation potential of industry clusters by transforming them into a collaborative organization to achieve long-term attainments. This is not easy, particularly because of the loose and structural asymmetric constitution of clusters, which nonetheless can be leveraged for innovation (Bengtsson and Sölvell, 2004). Different perspectives can deliver innovation through cross-pollination, when value creation through collaboration is achieved (Hansen and Nohria, 2004).

Therefore, first a systematic literature review was accomplished by using key words as innovation, industrial cluster, supply chain, virtual organization. Then MCDM, AHP, Electre were added to the key words. After an initial screening, a total of 176 references were looked at in detail, and as a result 97 references were utilized, whereof the majority were scientific papers, except five books, two reports and one workshop. Then, the idea of iCAT was born as a system and a tool for intelligent cluster assignment based on fuzzy AHP.

Furthermore, the problems in cluster and strategic objectives were discussed during the strategy workshops of SAHA (2015) in Istanbul, Turkey, while individual interviews were done with cluster members. After that, the hierarchy of iCAT was further developed by the input of 15 senior managers/specialists working in the collaborative product development environment in a Turkish cluster. Some of these companies are technology focussed SMEs based in a technology development zone, while others are regular SMEs and major OEMs in industry zones. Their common attribute is that they either operate in aerospace and defence, or they are from automotive and want to penetrate into this segment. There was no anchor firm of the cluster that it was a self-sustaining organization. Finally, this idea was discussed based on a value chain analysis for differentiation (Ucler, 2016) at the 22nd ICE/IEEE International Technology Management Conference, ICE 2016 in Trondheim, Norway. All the data gathered from the literature, interviews and the workshop were used to synthesize iCAT as explained in next section.

iCAT

In the past, monitoring was the main task of cluster managers (Tilson, 2001). Today, cluster managers are project managers (Ingstrup and Damgaard, 2013), driving shared production actively (Jirčíková *et al.*, 2013). Clusters have a cost, resource, or innovation typology, where the reality is a mixture (Seeley, 2011). Consequently the cluster managers need to set clear targets for innovation. Hence, it is obvious that the collaboration among cluster members has to be increased (SAHA, 2015), which requires an institutional environment (Arikan, 2009). Lima and Carpinetti (2011) define clusters as a regulated trust environment for collaboration, where NPD, new technologies, and new business models can be developed (Garetti and Taisch, 2012). Consequently the main idea of iCAT is to distinguish cluster members, who are open for and willing to realize collaboration and possess the means to do so. These members shall be then preferred over others in joint projects by an assignment process, where the proactive CM can pull the cluster.

Such a cluster is a collaborative network, which can function as a virtual breeding environment (Eschenbächer and Zarvic, 2012; Cheikhrouhou *et al.*, 2012), i.e. a suitable organization for innovative NPD. Taticchi *et al.* (2012) and Saetta *et al.* (2013) conceptualize this as a virtual enterprise, whereof the cluster manager is simply leading and coordinating this distributed organization. This is not an easy task and requires system-building (Planko *et al.*, 2016), which can be done with quasi-hierarchical chains, dealing with high-competency requirements (Humphrey and Schmitz, 2002). There are many attempts to deliver a collaborative virtual engineering framework (Dryndos *et al.*, 2008; Kazi *et al.*, 2009; Patel *et al.*, 2012) based on information and communication technologies (ICT) to deliver innovation (Saetta *et al.*, 2013). However, they only aim to integrate the work environment virtually and do not have a management function or an MCDM capability for assignment. While addressing strategic objectives of the cluster, usual procurement constraints such as financial, quality or capability-related aspects shall be respected as well. As a result, fuzzy AHP was preferred as the analytical MCDM tool for iCAT, supporting the assignment of work packages and daily routines of monitoring and management. Consequently, iCAT is constituted by the intersection of managers, developers and participants (Figure 1).

There might be partial analogies with the supply chain literature; however, to the best of the author's knowledge there is no other equivalent model to iCAT. In order to synthesize the iCAT model by quantified dimensions, both the cluster literature and the supply chain literature were looked at. Four dimensions besides pricing were consolidated after careful consideration of the determinants for the supplier selection problem of Ayag and Samanlioglu (2016): first, iCAT shall enable shared resources (Porter, 1998) as a cluster allocation tool. Then, the effective facilitation of existing free resources delivers the required

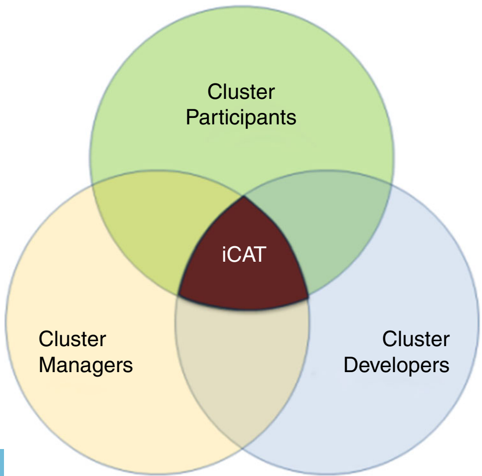


Figure 1.
Positioning of iCAT

short lead times (Choi and Hartley, 1996). Therefore it is assuring a uniform distributed, constant work load of members, where specific tasks or jobs can be distributed to several companies to increase participation. This gives a stable income spread over members in the time horizon. Second, iCAT is selecting the companies based on their capabilities (Choi and Hartley, 1996), where a production-only company and an engineering organization contributing to the vision are not the same. This is a kind of reverse discrimination for the further development of added value, i.e. companies with innovation potential are preferred for sustainability. Third, the quality is closely tracked (Choi and Hartley, 1996; Bergman and Lundberg, 2013), which is mandatory for long-term success. This demonstrates the required reliability (Huang and Keskar, 2007) and combines the delivery performance with the quality performance, which are set as supplier criteria by Sevkli (2010) as well. Choy *et al.* (2005) categorized suppliers as competitive or collaborative, which is respected here as well; the fourth dimension is the collaboration (Spekman, 1988; Emden *et al.*, 2006), which directly leads to NPD and innovation over shared knowledge (Lima and Carpinetti, 2011) and mutual knowledge generation (Casanueva *et al.*, 2013).

All these dimensions were merged in iCAT, in which fuzzy AHP engine determines the best distribution of the work by facilitating the dynamic information from the cluster database (Figure 2). Pricing shall be one of the least important selection items (Choi and Hartley, 1996); it was not considered as a standalone dimension to prevent its dominance, but it was reserved for the succeeding normalization of the weighing process. The hierarchy of the assignment process (Figure 3) was implemented with these dimensions in the first level and their breakdown in the second level. Only resources dimension was considered without a further breakdown, represented by the available free capacity.

De Toni and Nassimbeni (2001) distinguished between production and engineering capabilities that the branch of capabilities was split accordingly. A further break down of these sub branches can and shall be done per project requirements. Only suitable companies satisfying all required capabilities have to be considered. Therefore a work breakdown into work packages with isolated capability requirements may be carried out to assign work packages individually. Then, cluster members with a deep vertical specialization on a narrow band can still be assigned partially.

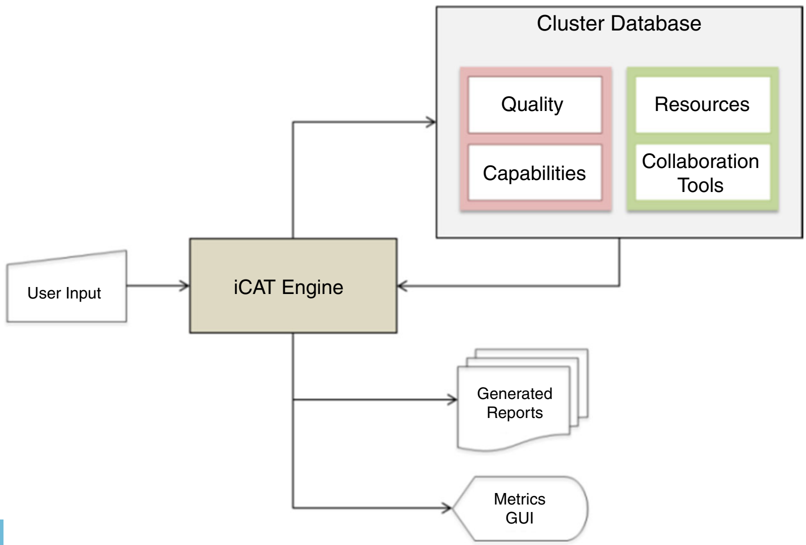


Figure 2.
The iCAT engine

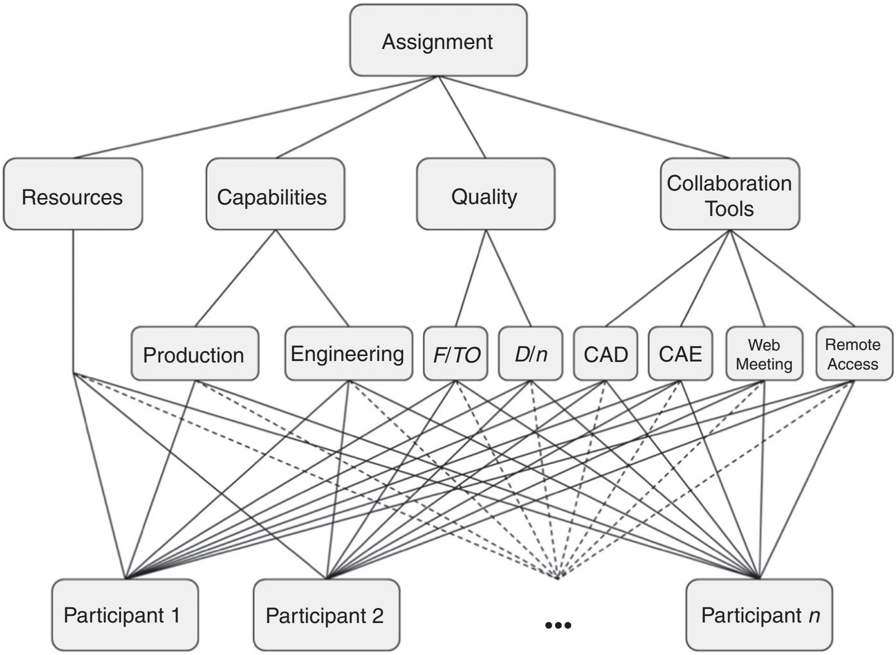


Figure 3.
The hierarchy of the assignment process within the cluster

The second level below the quality branch contains a set of KPIs, which may be determined by cluster managers and cluster developers. In general, Choy *et al.* (2005) expressed the quality performance as delays and number of defective items, which can track rejections or after sales metrics such as durability (Palanisamy and Abdul Zubar, 2013). This was also indicated by questionnaire participants that the number of faulty outputs per turnover (F/TO) and the number of total delay days per number of work orders (D/n) were set into the quality break down. While F/TO can be measured by the number of corrective action forms, D/n per trailing 12 months can be calculated, which represent the probability of failures $P_{F/TO}$ and $P_{D/n}$, normalized by the size of the business. A scale factor s was introduced for the compensation of the nature of the specific work, and equally weighted complements $P^c_{F/TO}$ and $P^c_{D/n}$ were used in iCAT to have a positive weight as:

$$w_Q = \frac{1}{2}\left[\left(1 - \frac{s \times F}{TO}\right); \left(1 - \frac{D}{n}\right)\right]$$

Collaborative technologies lead to innovation over shared knowledge (Lima and Carpinetti, 2011). Thereof Corallo *et al.* (2009) pointed out that the engineering knowledge can be captured and spread by using computer aided design (CAD) and computer aided engineering (CAE). Furthermore the ease of access to collaborative intelligence is very important (Choy *et al.*, 2005), which can be supported by web meeting and remote access capabilities (Cheikhrouhou *et al.*, 2012). Consequently CAD, CAE, web meeting and remote access were set under collaboration tools in the second level of the hierarchy, where normalized seat numbers are to be used.

Since data are captured collectively, iCAT grows over to an enterprise knowledge capture tool with various access rights (Figure 4). While cluster developers can create, modify and populate the iCAT matrices, managers and participants can only insert/read

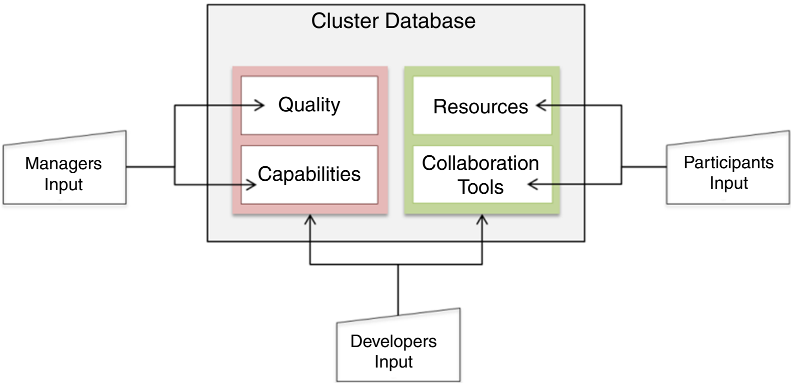


Figure 4.
The cluster database of iCAT

data for quality metrics, work load and tools in real time. It shall be noted that some of the participants and managers can act in the developer level as well. An auditing function is also foreseen (Figure 5) to avoid deviations and inconsistencies. iCAT has to be initialized first to determine the weights by a team of experienced CM personal, members and when required external consultants, who are designated here as developers. The consistency of the fuzzy comparison matrix has to be checked with the approach of Alonso and Lamata (2006). When required, iterations may be made to minimize inconsistencies. Then the project work-break-down has to be made, followed by the assignment based on the assessment with price normalization.

Illustrative example of iCAT

First the initialization was made with an online questionnaire, applied to selected managers, R&D specialists, and related academic members acting as consultants. The questionnaire did use the linguistic scale of Bozbura *et al.* (2007) with fuzzy numbers (Table I) to compare

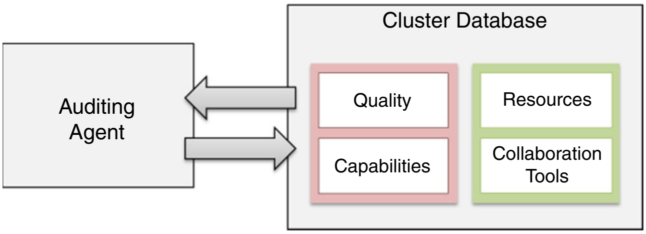


Figure 5.
The auditing function within iCAT

Table I.
Applied linguistic scale in iCAT questionnaire

Linguistic scale	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Absolutely less important	(2/7, 1/3, 2/5)	(5/2, 3, 7/2)
Very strongly less important	(1/3, 2/5, 1/2)	(2, 5/2, 3)
Strongly less important	(2/5, 1/2, 2/3)	(3/2, 2, 5/2)
Weakly less important	(1/2, 2/3, 1)	(1, 3/2, 2)
EQUAL	(1, 1, 1)	(1, 1, 1)
Weakly more important	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly more important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strongly more important	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Absolutely more important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

the four dimensions within the first level of the hierarchy (Table II), which normalized eigenvector $\overrightarrow{w_{L1}}$ was determined in the second iteration after defuzzification as:

$$\overrightarrow{w_{L1}} = \begin{pmatrix} 0.282 \\ 0.267 \\ 0.268 \\ 0.184 \end{pmatrix} \text{with } \lambda_{\max,1} = 3.064 < 4.273 \text{ for } \propto\ = 0.1$$

In the second level the comparison of production and engineering capabilities resulted in 0.39 and 0.61, respectively. Then the collaboration tools were compared in the same manner (Table III) resulting in A_{L2Clb} with the defuzzificated, normalized eigenvector as:

$$\overrightarrow{w_{L2Clb}} = \begin{pmatrix} 0.351 \\ 0.287 \\ 0.160 \\ 0.203 \end{pmatrix} \text{with } \lambda_{\max,2} = 2.951 < 4.273 \text{ for } \propto\ = 0.1$$

Consequently the weighted hierarchy was determined as shown in Figure 6. The global prioritization vector $\vec{R}$ was computed with the multiplication of the weights on the successive branches as (0.282, 0.104, 0.163, 0.134, 0.134, 0.064, 0.053, 0.029, 0.037) for (resources, production, engineering, *F*/*TO*, *D*/*n*, CAD, CAE, web meeting, remote access).

Then cluster members were screened subject to fulfil project requirements, and three companies were qualified. The first company was a joint venture of a small engineering consulting company with an established medium-sized production-only company. The second company was a large organization with a good track record of design, engineering and production. The third one was a small company with a limited number of experts, but extensive knowhow and superior quality.

The evaluation matrix E was populated, where each line of the evaluation matrix did include partial scores of one company, corresponding to the global prioritization vector $\vec{R}$. Available free metal processing capacity per hour over total capacity was used for resources. The assessment of the production capabilities was based on the total number of existing welding procedures specifications (WPS), procedure specification records (PQR) and the number of available production machinery. Engineering capabilities were measured

Table II.
Fuzzy comparison in the first level

	Resources	Capabilities	Quality	Collaboration tools
Resources	1	(1, 3/2, 2)	(2/3, 1, 2)	(1, 1, 1)
Capabilities	(1/2, 2/3, 1)	1	(2/3, 1, 2)	(1, 3/2, 2)
Quality	(1/2, 1, 3/2)	(1/2, 1, 3/2)	1	(1, 3/2, 2)
Collaboration tools	(1, 1, 1)	(1/2, 2/3, 1)	(1/2, 2/3, 1)	1

Table III.
Fuzzy comparison in the second level

	CAD	CAE	Web meeting	Remote access
CAD	1	(2/3, 1, 2)	(3/2, 2, 5/2)	(1, 3/2, 2)
CAE	(1/2, 1, 3/2)	1	(3/2, 2, 5/2)	(1, 1, 1)
Web meeting	(2/5, 1/2, 2/3)	(2/5, 1/2, 2/3)	1	(1, 1, 1)
Remote access	(1/2, 2/3, 1)	(1, 1, 1)	(1, 1, 1)	1

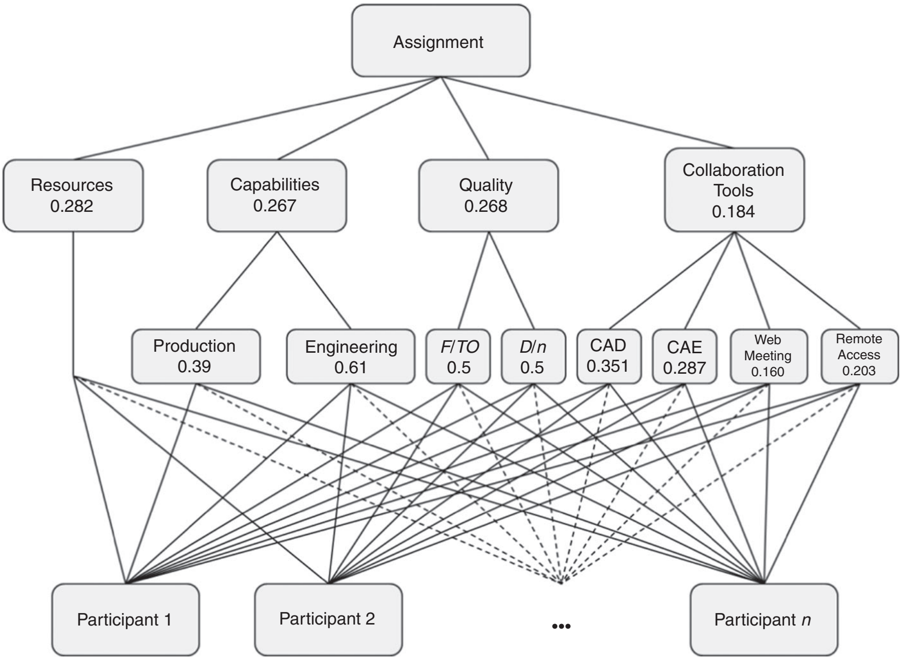


Figure 6. The weighted hierarchy of the assignment process

in total man-years experience of the engineering team, which included the time of university education as well. Standard KPIs of the companies were used to determine the *F/TO* and *D/n* numbers. Finally the collaboration tools were measured as the existing number of seats over the number of associates. All values were recorded in the evaluation matrix *E*, which columns were normalized (Table IV). The multiplication of *E* with the global prioritization vector $\overrightarrow{R}$ gave the scores vector$\overrightarrow{SCR}$ as (0.314, 0.308, 0.379). The associated cost information in US$ was captured in $\overrightarrow{c}$, as (256k, 298.5k, 310k), yielding $\overrightarrow{c}$ after normalization as (0.303, 0.342, 0.355). Then the adjusted, normalized score $\overrightarrow{SCR''}$ was computed as:

$$\overrightarrow{SCR'} = \begin{pmatrix} 0.314/0.303 \\ 0.308/0.342 \\ 0.379/0.355 \end{pmatrix} = \begin{pmatrix} 1.036 \\ 0.900 \\ 1.069 \end{pmatrix} \xrightarrow{normalization} \overrightarrow{SCR''} = \begin{pmatrix} 0.345 \\ 0.300 \\ 0.356 \end{pmatrix}$$

4. Results and discussion

It took more than two years to isolate the requirements of iCAT, to make the literature research, and to synthesize the iCAT model, which was successfully illustrated here. First, the numerical results of the illustrative example, then the innovation impact and finally further research possibilities are discussed next.

Assessing the numbers

Resources, capabilities, quality and collaboration tools were set in the higher level as criteria by literature research, which correlated positively with the questionnaire output. The requirements were also consolidated in SAHA (2015). There was just a small

Table IV. Summary of iCAT results

	Evaluation matrix E									Scores	Cost	Normalized cost	Final normalized score
Company	Resources	Production capabilities	Engineering capabilities	Quality (1-F/TO)	Quality (1-D/N)	Collaboration CAD	Collaboration CAE	Collaboration web meeting	Collaboration remote access	$\overrightarrow{SCR} = E \times \vec{R}$	$\vec{c}$ [kUS$]	$\vec{c}$	$\overrightarrow{SCR''}$
1	*0.345*	*0.066*	*0.419*	*0.236*	*0.424*	*0.156*	*0.574*	*0.310*	*0.101*	0.314	256	0.303	0.345
2	*0.138*	*0.808*	*0.452*	*0.315*	*0.134*	*0.511*	*0.100*	*0.162*	*0.212*	0.308	298.5	0.342	0.300
3	*0.517*	*0.127*	*0.129*	*0.449*	*0.442*	*0.332*	*0.325*	*0.527*	*0.687*	0.379	310	0.355	0.356
Global priority $\vec{R}$	0.282	0.104	0.163	0.134	0.134	0.064	0.053	0.029	0.037				

inconsistency in the first run during the iCAT initialization, which was then eliminated by consensus. Such iteration is normal in AHP (Saaty, 1990, 2003; Alonso and Lamata, 2006), and this indicated that these four dimensions were perceived as logical by the attendees. The outcome of the fuzzy AHP evaluation was that resources were weighted with 0.282 slightly higher than capabilities, quality and collaboration tools with weights of 0.267, 0.268 and 0.184, respectively. This is also logical since it is a constraint for production, and the main driving force of clusters is to enable shared resources (Porter 1998; Lai *et al.*, 2014). If only the total free capacity would rationalize an assignment in the resources dimension, then large organizations would supersede small organizations.

Consequently the free capacity over total capacity was preferred in the resources dimension. Then the engineering capabilities were valued 56 per cent more than the production capabilities.

The expert team said mutually that production can be outsourced in routine work, but the knowledge of the product is critical. For the outsourcing qualification two main fields were perceived important, namely available machinery, i.e. shop floor constitution, and the capability to convert material with this shop floor to products, which were measured in the number of existing WPS and PQR qualifications. The experts claimed that co-design capabilities and the desired collaboration can be measured in engineering capabilities simply in total man-years. This confirms De Toni and Nassimbeni (2001), who considered the experience of suppliers as invaluable.

The experts adopted standard KPIs as in Choy *et al.* (2005) and classified failures and delays equally important in the quality dimension. CAD was perceived as a standard collaboration tool with a higher weight, closely followed by CAE compared to web meeting and remote access. When the reason was asked, they designated CAD as a prerequisite of the other tools. The virtual enterprise literature places a great emphasis on streamlined tools that can work together (Dryndos *et al.*, 2008; Kazi *et al.*, 2009; Patel *et al.*, 2012; Saetta *et al.*, 2013); however, while accepting the compatibility is important, the experts did not perceive this as a barrier due to the wide standardization of tools. Thus only their existence was focussed on as an indicator.

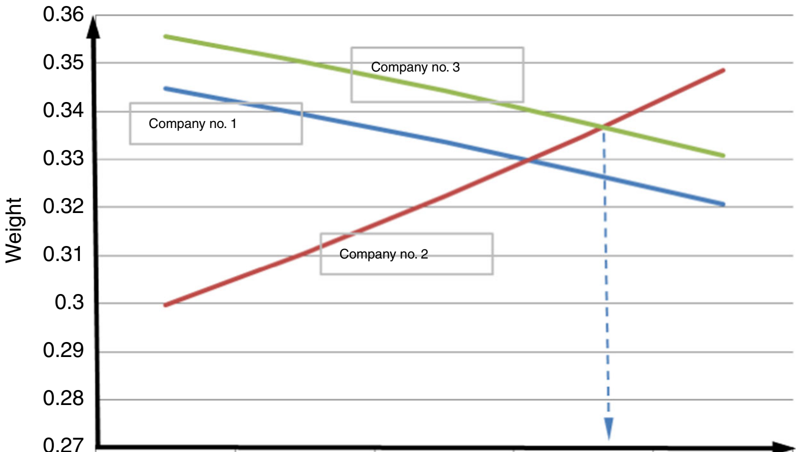
Weights were consolidated in the prioritization vector, where in the first run it was seen that the collaboration tools were not weighed too high, but this was relied to the fact that the engineering capabilities did contribute to the same target. When companies have engineering capabilities in CAE, this mean they can make structural design and virtual prototyping contributing to the engineering capabilities as well. Indeed engineering capabilities (0.163) and all collaboration tools (0.184) did contribute to the assignment with a cumulative weight of 0.347. This indicates that the engineering capability and available tools for collaboration were highly rated as expected from the research of Emden *et al.* (2006), who directly relate collaboration and value building in NPD.

The population of the evaluation matrix captured the status quo: the first company was a medium-sized organization with resources idle. It had limited production capabilities, but high engineering capabilities. Both delays and failures were intermediate. A limited number of CAD tools, but a high number of CAE tools were available. Web meeting was used at a high level, but remote access was restricted. The second company was a large organization with a high utilization of resources. It had very high production capabilities and high engineering capabilities. Delays and failures were high due to the workload. A high number of CAD tools, but a high number of CAE tools were available. Web meeting was used less than the first company, but remote access was accessible to a higher population. The third company was a small, but very specialized organization with the lowest utilization of resources. It had very intermediate production capabilities and lower engineering capabilities due to the restricted number of associates. There were almost no delays and failures. CAD and CAE usage was intermediate, but both web meeting and remote access were accessible to all associates.

As a result the third company from the aviation sector was selected with a normalized score of 0.356. The higher cost, limited number of engineers, restricted shop floor and resources of the third company did not prevent it from being selected. The selection was based on high collaboration capability and superior quality. This is also in-line with the findings of Rose-Anderssen *et al.* (2011) for aerospace supply chains, where high level of collaborative relationship is preferred over the price. Since the third company was working exclusively for civil aviation, the planning and engineering phases were done excellently. Consequently there were practically no faults or delays. The other two companies did operate mainly to the general metal industry with a lower quality. The third company was using concurrent engineering and this was the reason of higher collaboration over web meeting and remote access, while the other two companies did only collaborate on design gates. All in one the selection was logical and differentiating as claimed.

Labib (2011) made a sensitivity analysis of AHP criteria to assess changing environments. Similarly, a simulation was made to evaluate several pricing scenarios, where only a high discount of over 17 per cent could have have had change this assignment given inelastic pricing of the other two parties (Figure 7). In the case of a 5 per cent discount of the first company and inelastic price of the other two parties there would have been an assignment to the first company, where its price would be 19 per cent less than the third company. When in this case the third company would have shown even a very small price elasticity of 3 per cent, than it would have got the assignment again. As a result iCAT was considered to achieve a robust assignment in terms of price interaction.

The interaction of the company size with the assignment process was also looked at. First the resources dimension utilizes free capacity over total capacity as a percentage. Thus large companies are not privileged, but companies with a lower workload and a good quality. The turnover normalization and the scale factor in the quality dimension prevent size interactions. The capabilities in a large company might be higher due to the knowledge accumulation over time. This and lower prices due to mass production might give an advantage, which is in fact fair and shall be treated as a natural competitive advantage.



	0%	5%	10%	15%	20%
No. 1	0.344687806	0.339335627	0.333580396	0.327374804	0.320663835
No. 2	0.299677968	0.310552298	0.322245532	0.334853791	0.348488852
No. 3	0.355634226	0.350112075	0.344174072	0.337771406	0.330847313

Figure 7.
Impact of discounts of the second cluster member

Nevertheless it is then still not dominating due to the availability of the other criteria. Indeed the biggest company with higher workload resulted in the last ranking with a weight of 0.300. It was not practiced in this simple example, but a further breakdown of work packages could be made, which would enable the enclosure of big production focussed companies which need a high workload to remain competitive. This could also eliminate problems associated with higher scores of very large organizations with many associates due to additional areas of expertise.

Innovation impact

First of all the usage of iCAT is changing the way of working in clusters that it is according to OECD (2005)'s subject innovation itself. Then it is driving towards innovation. This is exemplified here by setting the CM to a proactive role. Under his leadership, iCAT acquires information, processes it with the fuzzy AHP engine and makes an evaluation. Per definition this designates it as intelligent. The fuzzification is further contributing to the intelligence, since it is dealing with uncertainty.

The novelty of this intelligent decision support tool is that it can distinguish collaborative companies capable to contribute to long-term commitments. Indeed, the decision in the example did differentiate the small company with a higher collaboration potential and superior quality, which was in-line with the objectives of iCAT. Such companies are good candidates for high-technology outputs and innovation over the long run. Usually, economizing strategies might prevent them from further development. However, iCAT assures that such companies do get a higher chance in job assignments despite higher costs. Such skilled companies are good candidates in absorbing, generating and sharing knowledge. When there are many of them within clusters, this delivers an incubation environment for ideas, and thus innovation. Furthermore this collaborative character entitles the cluster for strategic partnerships and qualifies it according to Choy *et al.* (2005) for product innovation in NPD.

The real impact of iCAT process is that it is not an ad-hoc solution. During continuous usage it would trigger cultural transformation towards collaboration and will accumulate this capability within the cluster. Even during the simple run there was continuous information flow from managers, participants and developers, keeping the system up-to-date. Hence, the system motivated cluster members for active participation. This did deliver a shared context in a virtual space of interaction, which is called by Nonaka *et al.* (2008) as the "ba", enabling innovation by the socialization, externalization, combination, internalization model (Nonaka and Takeuchi, 1995). In the long term its outcome is mutual knowledge generation leading to innovation (Casanueva *et al.*, 2013).

Another important finding was regarding the contribution of the iCAT data flow: when the metrics of cluster members were streamlined into iCAT, a valuable database did arise, which unites the cluster to a single organization. Especially the small company was not able in the first run to verbalize its capabilities with a breakdown, and iCAT did contribute to bring it closer towards the systematic approach of large industrial organizations. This need was also identified by Saetta *et al.* (2013), trying to enable innovation in collaborative SMEs by transforming them to a virtual organization with metrics, which can be used as cluster KPIs for further analysis. This underlined the proactive role of the CM as a leader. According to Stamm (2003) leadership and a vision are vital differences of innovative organizations, which is directly addressed by iCAT. Besides forging the cluster into a virtual organization, this new leading role of the CM can leverage innovative new products defined within the cluster. Then the cluster may be converted to a functioning organization with its own object innovation capability. During that, tacit knowledge would be collected and shared, which according to Perez-Araos *et al.* (2007) would lead to innovation as well.

Another important finding was the willingness of the cluster members. In all of the interviews it was seen that cluster members were actively looking for possibilities to enhance innovation potential that they are ready to participate in systematic approaches. They were open for working in cross-organizational projects. This might be on the one hand explained by the nature of the cluster, i.e. the aerospace value chain requires collaboration at a higher level (Rose-Anderssen *et al.*, 2011). On the other hand, self-sustaining cluster organizations need to deliver innovation naturally, which reflection on organizational adaptation might be the case here. The majority of existing clusters in developing territories are pulled by large investing organizations (Kuchiki and Tsuji, 2008), where the economizing strategies are limiting (Ursino, 2015). However, there was no anchor firm in the illustrative example. Consequently, the cluster members needed to generate new businesses by themselves, and thus they were more open to collaboration. Nevertheless the willingness indicated the positive perception of the logic of iCAT as well. All in one this implied that the iCAT model is suitable to drive innovation potential in clusters in developing economies, especially when there is no dominant anchor firm. This is in fact not a limitation, but a planned focal point of this research. Other cluster organizations, which are acting in the supply chains of large OEMs, were simply not focussed on, and they shall be addressed by open innovation (Chesbrough, 2006) and innovation management systems of larger organizations (CEN/TS, 2013). Nevertheless there are similar challenges within these supply chains, especially in the fuzzy front end of NPD (Wovak *et al.*, 2016) that researchers from this area might benefit from this research comparatively.

Also the perceptions of attendees were that such a transparent system is "fair" and they would accept the outcome. They did use the information feed as an opportunity to evaluate their status quo. Also the model of iCAT was understandable for them that it enabled transparency and delivered a trust environment, which are prerequisites for efficient collaboration (Lima and Carpinetti, 2011). This is important for innovation, but also for the long-term prosperity of the cluster as well. Arikan (2009) pointed out the need of a management system for balanced job assignments in knowledge-based clusters to prevent advanced knowledge assets from leaving the cluster. The conception of iCAT specifically addresses this problematic, which was supported by this positive perception on the field as well.

Further research

iCAT can deliver the transformation of the cluster towards a united virtual organization, which can develop and produce new products. Such a task is involving a decentralized production network, which requires enterprise resource planning (ERP) and product life cycle management (PLM) supporting the virtual supply chain (Brettel *et al.*, 2014). ERP and PLM tools did exist in the members of the example cluster. Nevertheless, none of the experts or managers participating focussed on these tools. It could be worth to look on the interaction of such tools with collaboration in further research. Also a wider set of selection criteria can be looked at. Especially traditional supplier selection criteria also include the financial stability (Huang and Keskar, 2007; Kuchiki and Tsuji, 2008). None of our experts indicates this as important for the innovation impact, but this could be a further point to think about. Then, there are cyber-physical-systems (CPSs) enabling communication between humans, machines and products, which will be part of collaborative networks of Industry 4.0 (Brettel *et al.*, 2014). For sure CPSs and their impact on cluster organizations are a further research area.

Despite illustrated by an example within a specific market from a developing region, the concept delivers a generic framework. Moreover the positive perception within the international conference indicated a good fit. In fact the initialization of iCAT is meant to go over perceptions, cluster specific needs, and structural asymmetries of members, providing an adoption capability to local circumstances. Consequently, it was deliberated on cross-sectional perspective as satisfactory. Additionally iCAT is not firm and fixed. It is like a workbench and it can be evolved over time. Since iCAT is scalable, criteria can be added in expense of expert work and computational cost. Usually, a limit of ten alternatives is associated with AHP (Bozdag *et al.*, 2003) that the hierarchy in iCAT shall be kept as lean as possible.

5. Conclusions

Industrial clusters are a popular way to support competitiveness by shared resources. They mainly deliver products and services in a reactive manner, where the cluster is only facilitating. However, they are more than vertically integrated supply chains, targeting added value by joint initiatives. When the members can unite and the cluster transforms towards a virtual organization, a collaboration environment can be enabled. Then, ideas can be circulated and cross-fertilization can lead to innovation. This enables NPD within the cluster and the penetration into new markets, further leading to sustainability.

Nevertheless, this is not an easy task, complicated by economizing strategies, zero-profit conditions and singular preferences of members. In order to drive the desired shared production, but also to empower a virtual breeding environment for innovative ideas, the cluster must be upgraded to deliver an accessible institutional environment based on openness and trust, enabling information circulation among members. This is only possible within a structured system under leadership of the CM, driving proactive business development for the cluster. Then, the cluster can be differentiated by assigning work packages in cross-organizational projects preferably to collaborative members with a higher innovation potential. This in turn delivers a systematically innovative organization in the long run, but it requires system-building with a fair and robust model.

To synthesize such a model, first the intersection of the literature was looked at for innovation, industrial clusters, supply chains, virtual organizations and MCDM. Then the required dimensions of the system were consolidated using the literature, and thereafter a workshop and an iterated questionnaire were used to form a fuzzy AHP system, referred as iCAT. It was conceptualized as an adoptable workbench, integrating: resources, capabilities, quality, and collaboration on the higher level, which criteria can be set in the lower level for individual clusters. These dimensions are all implemented within the database structure of iCAT, where individual members do insert their status quo that the information of the whole cluster is captured. Consequently the cluster can be monitored, and companies can be assessed with real-time data. To deliver an illustration, iCAT was also run within an example successfully, where the assignment respected a healthy mix of available free resources, quality, knowhow and collaboration, and the effect of the price was not dominant.

This approach differs from the literature, which points out to the need of a system for both the cluster management and innovation. However, there is no specific approach for such a system for clusters. This gap is explicitly addressed by iCAT, supporting CM to differentiate by proactive leadership. If all isolated dimensions are respected in the MCDM, then the resulting assignment respects reverse discrimination, enabling capability building. However, it is done in an effective and transparent manner, which is acceptable for members. Since iCAT is integrating the cluster members in a collaborative environment, it is leading towards a cooperation base enhancing the potential for innovation and NPD.

iCAT is utilizing live data from the cluster members that it elaborates the participation of all members. It is processing data to form an intelligent decision. Capturing and storing the knowledge across the cluster, it supports the CM in strategic decisions and transforms the cluster manager to a proactive coordinator and a business developer. The top down information-flow through traditional supply chains might result in some collaboration. However, iCAT becomes a hub for the information, thus it is enforcing proactive collaboration. Additionally instead of the traditional concept of an anchor firm pulling the cluster, the cluster manager itself gets the anchor in this model. This transforms the cluster over time to a virtual organization. It was proven to be robust against aggressive pricing policies or size interactions, which was demonstrated by the example as well. Moreover attendees showed a high willingness to participate and emphasized a fair perception. All in one, the strategic selection was in-line with the collaborative NPD and innovation perspectives in the longer run.

Consequently, this model helps clusters and small organizations to upgrade for innovation. Cluster members are actively looking for possibilities to enhance innovation potential that they are ready to participate in systematic approaches. iCAT delivers a system to manage the internal work package assignment across the cluster, but it also delivers a strategic tool for organizational transformation towards a collaboration base. Thus, this work can also contribute to the supply chain literature with respect to supplier development programmes interested in co-design. Beyond enabling the multidimensional evaluation of alternative cluster members, it is an integration platform, targeting the management of the cluster as a whole. Consequently, the CM can lead the cluster as a virtual organization, which is united with a shared database, streamlined quality metrics and strategic vision, which is further differentiating the cluster contributing to the strategic innovation perspective. Collaboration and the knowledge distribution also deliver a shared vision with clear innovation targets.

One improvement area was determined during the initialization of the system, where the questionnaire data were incorporated. The experts did achieve a consensus after iterations, where the response time was too long. The usage of an ICT system could enhance this. Moreover the financial status of the supplier was not considered as a requirement, but it is a common attribute in the supply chain literature. None of the experts did mention this dimension, which could be looked at as well. Also the impact of PLM and ERP was not covered nor discussed, which could be investigated as well. However, it has to be mentioned that there should be a trade-off between computational efficiency and the number of criteria. Finally the number of experts could have been larger or different cluster typologies could be looked at to further support the generality and validity. Nevertheless, this paper only utilizes an illustration example with a good fit to clusters without a dominant anchor firm, and it aims to demonstrate the basics. A multiple run on different typologies was not possible due to practical reasons, but iCAT was deliberated on cross-sectional perspective as satisfactory for different sectors in developing economies, since it has a generic framework, which can be initialized according to local circumstances, which was also supported by the evidence during the discussions at the international ICE Conference.

As a result, innovation and NPD are vitally important for the sustainability of industrial clusters, where iCAT delivers a practical management support tool based on fuzzy AHP. The implementation of iCAT transforms the CM to a proactive leader and a collaborative environment is enabled, uniting the cluster to a virtual organization. It forces systematic information flow delivering a quasi-physical space for interaction that innovation can be expected as an output, delivering further added value. Cluster members, who want to get new assignments in joint undertakings, need to take care of collaboration, long-term quality metrics, and their capabilities. From this perspective the adaptation of iCAT encourages cluster members, particularly SMEs, for further development.

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