Planning distributed innovation processes in Virtual Organisations by applying the Collaborative Network Relationship Analysis

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Abstract: The planning of distributed innovation processes in virtual organisations is a necessary step in the development of new and advanced products and services. In the past most research on innovation processes were focused on multinational companies with an intra-organisational perspective. The phenomena of innovation processes in networks – with an inter-organisational perspective – have been almost neglected. Collaborative networks are a new application field for such distributed innovation processes where specifically the Virtual Organisation (VO) offers a high potential for new business opportunities. The Collaborative Network Relationship Analysis (CNRA) is specifically designed for such networked organisations. It is shown that a qualitative planning of collaboration intensities can support business cases by proving both, knowledge and planning data. The consolidated findings of Social Network Analysis (SNA) are used as basis for the CNRA. A formalised example shows that certain aspects used in the SNA can be re-utilized resulting in the proposal of a new indicator addressing the CNRA.

Keywords: Collaborative relationships, Collaborative Network Relationship Analysis, Network Analysis, Virtual Organisation, Innovation, Innovation Process

Introduction

Companies are forced to improve their innovation cycles in order to stay competitive in the global market (Gassmann and Zedtwitz, 2003; Segarra, 1999). A good example for a short innovation cycle in a new market segment shows the introduction of the iPhone. Apple was able to create a world-wide successful mobile phone from scratch. The success of the iPhone is based on an attractive design, the concept of being permanently online and a new and innovative user interface technology (Varian, 2007; Linden et al., 2007; Gassmann and Sutter, 2008). One important approach Apple applied was the integration of experienced partners with complementary core competencies into a collaborative network of organisations. The aim of that collaboration was the design of a new and innovative product by sharing and combining previously isolated and distributed knowledge. This successful example demonstrates the potential of collaborative working in networks on innovation projects. As an unpleasant side effect, collaboration within innovation projects always includes an increasing number of risks, such as lack of synchronisation due to the distribution of tasks and responsibilities, competing goals of the collaborating partners, or the possible loss of intellectual property of specific partners. These examples show that the challenge within networked organisations is to exploit the collaboration benefits while coping with the risks.

The principle of a Collaborative Network Organisation (CNO) as new organisational framework has been introduced by a number of authors like Camarinha-Matos et al. (2009), Schuh et al. (2009), and Chesbrough (2003). As a special type of the CNO, the Virtual Organisation (VO) represents the task specific, short term alliance between independent companies. Due to its temporary character, the VO is the suitable collaboration type to create collaborative innovations based on identified business opportunities (Seifert, 2007). Within a VO the analysis of collaborative relationships is a very important subject which needs further investigation.

This paper proposes an approach for planning and to maintaining the individual relationships within a VO on an operational level, based on characterising inter-organisational relationships. After a discussion of how quantitative and qualitative approaches can be used to support the analysis of networks, specific attention is put on both, the conceptual presentation and a basic mathematical representation of the approach. The application of the proposed approach – the so called Collaborative Network Relationship Analysis (CNRA) – will lead to an improved planning of distributed innovation processes in the operation phase of Virtual Organisations. Finally, the CNRA is discussed formally by adapting the mathematical logic of the Social Network Analysis (SNA) to define a new indicator.

Analysis of social and organisational relationships

The analysis of collaborative network relationships has been introduced with the developments of the Social Network Analysis (SNA, e.g. Wassermann and Fausst, 1994). The SNA was focusing on quantitative approaches analysing nodes and edges of graph representing a network. Recent qualitative approaches have been developed to supplement the quantitative approaches. This section describes quantitative and qualitative approaches illustrating their potentials and limits. The discussion is based on an organisational perspective.

Quantitative approaches

The application area of the network analysis is very broad (Hollstein, 2006). Especially the developments in the SNA led to many approaches (Wassermann and Fausst, 1994) and a high number of tools (CASOS, 2008). Meanwhile, a number of business oriented study results are available focusing on the application of the methods of the network analysis in companies (Rank, 2003; Wald, 2003). Global intra-organisational networks have been analysed such as of the BASF corporate group. A recent study discusses the usage the centrality and density of individuals in the Siemens Corporation (Ellmann, 2008). She has empirically analysed two indicators from the SNA out of many in the framework of the quantitative network analysis. Consequently the methods of the Social Network Analysis arrived in the framework of organisational studies. In general the quantitative network analysis is divided into three phases: data acquisition, data representation and data analysis (Renz, 1998, p. 114). There are different methods available for quantitative data collection, structuring and evaluation.

The quantitative network analysis captures network structures by using mathematical calculations which implies a very formalistic way of handling network relationships. In fact this has been the basis for a lot of criticism towards quantitative procedures of the network analysis (Renz, 1998). Basically, two points can be summarised:

- Too Static: Due to the different measurement of various characteristics, the procedures of network analysis are able to construct networks in deep according to their structure but content, and dynamics of relationships cannot be captured (Sydow, 1992). Additionally, lacking consideration of context awareness seems to be a problem (Renz, 1998).
- Difficult translation from experiences into numbers: The quantitative description of qualitative characteristics by using indicators is often difficult or – to a certain extent – impossible. An actor that is acting a long time in the network can be a rookie in network analysis methods. But – and this is more important – such a rookie can most probably better understand and translate the network behaviour due to his experience. Therefore, he might be the better network analyst.

The quantitative methods for network analysis can be used specifically in those situations in which already a body of knowledge about the behaviour of the network is available. This knowledge can be used within a precise analysis leading to concrete results. Additionally, a narrow and precise research question should be formulated to make it understandable. In case of rough investigated research fields and non precise research questions the quantitative methods are not recommended. The research field should not have too many explorative elements (Renz, 1998).

Qualitative approaches

Indeed it is a question of the massive criticism towards the quantitative network research that qualitative network analysis is getting increasing attention. In comparison to quantitative approaches the usage of qualitative approaches is still in its beginning. Qualitative methods for network analysis aim to transfer the layman theories of members of the Virtual Organisation about relationship constellations in the network analytical outward perspective. Layman theories can be defined as knowledge from managers and employees judging and estimating about present and future organisational behaviour from organisations and people within networks. This knowledge is gained by intensively interviewing those people instead of simply sending questionnaires. Exactly this transfer can be seen as the main objective of qualitative network research methods.

The understanding and interpretation of the actor's behaviour is of high value for trying to create future scenarios (Hollstein, 2006; Renz, 1998). For this reason the qualitative network analysis can give direction for the network analytical research in general (Sydow, 1992). Instruments which are able to capture and analyse both, dynamic and temporal changes in the network are the biggest conceptual challenge for research activities (Jansen, 2006) and the qualitative network research offers opportunities for doing this (Hollstein, 2006). The qualitative network analysis can also be divided in data acquisition, data representation and data analysis. The main difference lies in the kind of instruments and the respective questions. Naturally, the qualitative network approaches are analysing different instruments focusing less on mathematical accuracy but more on gathering and understanding the layman theories – which are ideally logic and consistent. An overview about more qualitative tools for network analysis can also be found at Center for Computational Analysis of Social and Organizational Systems (CASOS, 2008) and Hollstein (2006).

For network modelling using qualitative research methods, the network researcher must enter the subsurface structure and the social reality of the network actors. This complex task gets even more difficult because of the lack of a common language between network actors and network researchers. While the network researcher is able to capture emotional and systematic characteristics of networks and to transfer that to a comprehensive language, actors within the network might not understand this. Additionally, it is very difficult to translate layman theories into a network described by a formal language. This is especially difficult because there is no commonly accepted network language allowing interpretation (Renz, 1998).

The qualitative network analysis highlights context conditions such as trust and emerging standards. The analysis can be used as a form for exploring new issues such as innovation processes. These analysis methods can be used for interpreting each actor, subjective perceptions and guided orientations (Hollstein, 2006). However, the results of the qualitative network analysis are always subjective because they are based on personal observations and estimates.

Need for organisational network analysis approaches

The discussion above shows the wide application field of both qualitative and quantitative methods of the Social Network Analysis. The quantitative approaches are very useful in stable network settings such as supply chains, but they are not very beneficial in unforeseeable innovation processes. Qualitative methods offer a high potential to better capture complex settings in distributed innovation processes (Eschenbächer, 2009). A first conclusion is that it can be beneficial to use qualitative approaches to capture the data and some simple quantitative approach to interpret it.

The state of the art as presented so far provides evidence that there exists no qualitative or quantitative method supporting a careful investigation of organisational relationships. One reason is that software tools to interpret complex data are only available very recently. Additionally, ICT (Information and Communication Technology) tools enabling inter-organisational networking are available only since a few years. These observations lead to the conclusion that there might be an opportunity for a new approach. Some authors like Sydow (1992, Ellmann (2008), Rank (2003), and Wald (2003) also suggest to extend the focus from simple SNA to an Organisational Network Analysis which is not focussing on the relationships between individuals but on organisational relationships. The advantage is not being dependent on a single person's opinion.

The Collaborative Network Relationship Analysis uses a mixture of both, qualitative oriented conceptual ideas and quantitative evaluation in order to understand and plan relationships between organisations.

The Collaborative Network Relationship Analysis

This chapter presents the Collaborative Network Relationship Analysis (CNRA) as a qualitative approach to support planning and maintenance of innovation processes.

Concept

The concept of CNRA is based on some assumptions and basic conditions. The main assumption is that a group of companies intend to cooperate. In other words they are not carefully analysing make-or-buy-decisions versus collaboration. The enterprises have simply decided to collaborate in order to bring together resources, knowledge and core competencies.
Figure 1 shows the general concept of the collaborative relationship analysis. First, the CNRA starts with the identification of the needed collaborative relationships between the involved organisations (Figure 1A). Second, it is necessary to identify and to forecast the needed interactions differentiated into six categories as shown in Figure 1B. All interactions of a collaborative relationship define an interaction group. Altogether six different categories of interactions can be distinguished addressing different kinds or types of interaction. Finally, in Figure 1C the collaboration intensity is specified (another assumption is that the collaboration intensity varies substantially within the different tasks in cooperation).

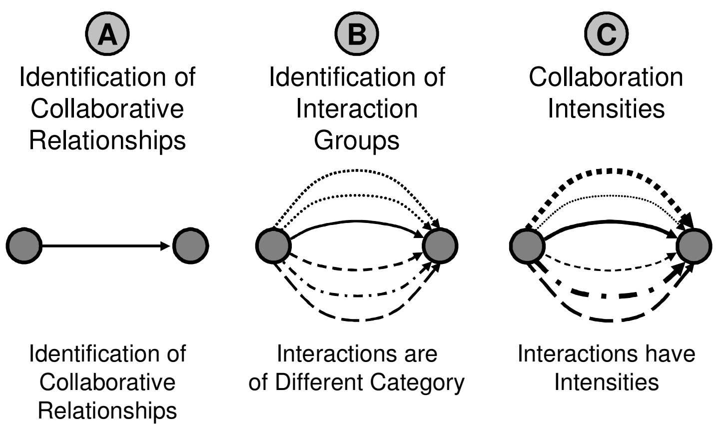

Figure 1: Concept of the CNRA

In the above Figure 1 graph theoretic concepts have been used to model real world entities. Nodes are used to model organisations and edges are representing collaborative relationships (Figure 1A) and interactions (Figure 1,B and C). The single categories are explained in the next chapter. As the edges representing an interaction group all have the same source and destination node (multi edges), the resulting graph is a multi-graph.
More information and a detailed description can be found in Eschenbächer (2009). In the following section the focus will be on the investigation of the collaboration intensity.

Collaboration intensity

The idea of dividing collaborative relationships into grouped interactions has been introduced in the previous section. In order to define a numerical intensity for such collaboration, a five-step approach has been used. Figure 2 shows this approach to specify the intensities of collaborative relationships. Following this methodology a collaborative network planner will be able to identify the necessary relationships, break them down into a number of interactions and explore the respective intensities. This can be used as basis for planning the operation phase of a Virtual Organisation.

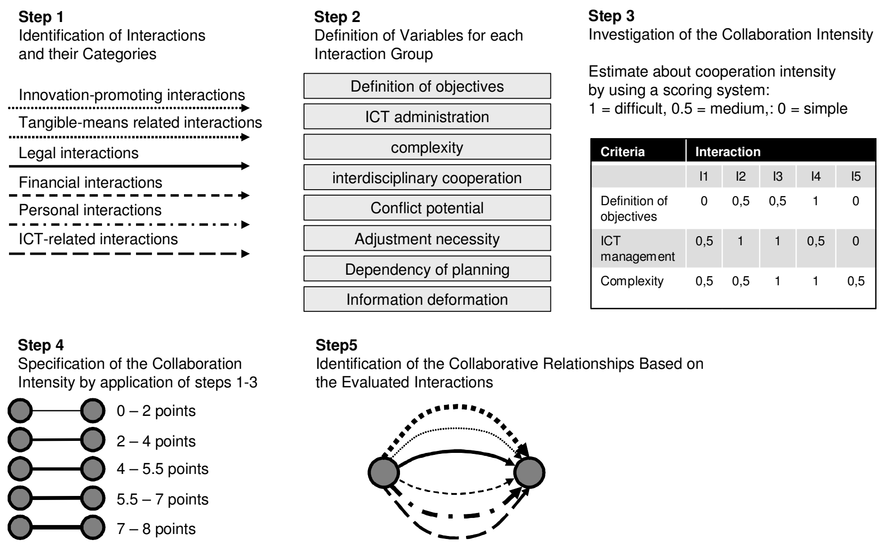

Figure 2: Method to specify the collaborative relationships and intensities

The five steps can be summarised as follows:

1. All identified interactions within the planned network are collected. Additionally every interaction will be specified towards one of the six categories. Each interaction belongs to one of the categories so that many interactions (shown as edges) can be placed between the nodes).
2. The variables are identified. Basically each of the six interaction categories has an own set of variables. In Figure 2 eight exemplary variables are presented.
3. The variables are evaluated by using a simple method. An estimation of the collaboration intensity is realised by a simple scoring system. This scoring provides an idea about the potential difficulty to conduct the interaction.
4. The collaboration intensity will be specified on the basis of the scoring result from the previous step.
5. In step 5 the collaboration intensities are specified with a very simple diagram showing six edges with different sizes and arrow types.

The approach suggested in Figure 2 is simplified and takes into account uncertainties about the exact behaviour of the organisations. The objective is to get realistic estimate about the operation phase of the VO by using heuristic methods to collect the information. Consequently the collaborative network analysis can be applied to better understand innovation processes in virtual organisations. The results can be used to have input for a more exact planning of resources, competencies and network interactions.

Mathematical model for collaboration relationships and intensities

In this section the method shown in Figure 2 is formalised in a simple mathematical approach based on the results of the social network analysis.

Mathematical foundation of the Social Network Analysis

Mathematical models play a significant role when analysing structural and functional behaviour of networks. The focus has been on social networks (Wassermann and Fausst, 1994), only recently the focus has been extended towards the organisational dimension (Ellmann 2008). Results about the application of mathematical models in organisations can be identified in several scientific studies (e.g. Rank, 2003; Wald, 2003). In such studies a selection of indicators has been used for a closer look into the networks. In practice the analysis of such indicators is very difficult because the considerations are mostly based on mathematical calculation of instable aspects such as density, centrality and others. Computer based software tools support such calculations (CASOS, 2009) but with the major drawback of transforming data into precise results which are often based on rough estimations.

To understand the general ideas behind these approaches a basic understanding on quantitative methods for the analysis of networks is needed. Consequently this section presents an overview about mathematical approaches. Based on these approaches a new indicator called *Collaboration Intensity* (between the nodes) is defined. The mathematical representation presented in the following is based on Wührer (1995, p. 100 ff.) which uses a coding showing the position of an enterprise i to another enterprise j. The coding is used to characterise a dyadic relationship between enterprises in a given network k consisting of N nodes. For simplicity an interaction z_{ijk} is 1 when it exists and 0 otherwise. Additionally, other typical relationship between the nodes may also be captured (Wührer, 1995; Knoke and Kulinski, 1982; Scott, 2005). The result of a network analysis provides a decomposition about centrality aspects and suggests a precise imagination about the reality. In the following, central indicators for characterising collaborative relationships between companies are explained using the notation of Wührer (1995).

- **Outward degree of nodes:** the degree of outward orientation $O_{Out_{ik}}$ of an organisation i is the sum of all relationships with other organisations j in a network k. From a mathematical viewpoint it represents the line total of an organisation i in a network k. In general k represents the different dimensions of relationships, which appear between the actors i and j. Different relationships such as capital-based relationships, trade-off relationships, know-how relationships, etc. can be distinguished. Not every organisation is integrated in every network k, in several networks it stays aside and has no connection to any member of such network, in other networks the organisation can be the central node in extreme cases. To summarise: The degree of outward orientation indicates how many nodes and edges are directed from the considered node.

$$O_{Out_{ik}} = \sum_{j=1}^{N} z_{ijk}, (i \neq j)$$

- **Inward degree of nodes:** Analogous to the outward orientation inward orientation can also be calculated. Generally, the inward orientation $O_{In_{ik}}$ of the node i represents the number of relationships from other nodes j to the single node i. In other words: the inward orientation indicates how many edges point on the considered node.

$$O_{In_{ik}} = \sum_{i=1}^{N} z_{ijk}, (i \neq j)$$

- **Network density:** The network density D_k of a network *k* indicates the fraction of all existing relations of all possible relations. It describes whether the network is very dense or if nodes are only loosely connected. The network density can only become 1 as a maximum.

$$D_k = \frac{1}{N^2 - N} \cdot \sum_{i=1}^{N} \sum_{j=1}^{N} z_{ijk}, (i \neq j)$$

- **Centrality:** The centrality is an essential concept to describe and analyse networks. The higher the centrality of a node the stronger it is linked in all network activities. The simplest indicator for a centrality index C_i is the fraction of all relationships of a node *i* of all existing relationships. The centrality indicates the number of all inward and outward oriented relationships in reference to all possible edges.

$$C_i = \frac{\sum_{j=1}^{N} (z_{ijk} + z_{ijk})}{\sum_{i=1}^{N} \sum_{j=1}^{N} z_{ijk}}, (i \neq j)$$

This short selection provides basic metrics for network analysis from a quantitative point of view. This kind of analysis is state of the art and has been used in different studies (e.g. Ellmann, 2008; Rank, 2003; Wald, 2003).

New Indicator: Collaboration Intensity

An issue which has not been formalised so far is the collaboration intensity of relationships between organizations. These relationships are modelled as edges between the nodes. In the following an indicator to formalise collaboration intensity is proposed using the same formalisation approach as Wührer (1995). Table 1 provides an overview on the symbols used to formalise the collaboration intensity and to relate it also to time and costs.

Symbol	**Description**
$\sum_{i=1}^{N} \sum_{j=1}^{N} z_{ijk}, (i \neq j)$	Number of considered Interactions
z_{ijk}	interaction *z* (between the nodes *i* and *j*) of category *k*
$x_{z_{ijk}}$	Collaboration intensity of interaction z_{ijk}
$t_{0_{z_{ijk}}}$	Starting point (in time) for interaction z_{ijk}
$t_{d_{z_{ijk}}}$	Duration of interaction z_{ijk}

$g_{z_{ijk}}$	Weighting factor of interactions z_{ijk}
$I_{z_{ijk}}(t)$	Intensity of interaction z_{ijk} at point in time t
$C_{z_{ijk}}$	Cost of interaction z_{ijk} during the duration $t_{d_{z_{ijk}}}$ of interaction
$c_{z_{ijk}}(t)$	Cost of interaction z_{ijk} at point of time *t*

Table 1: Formalisation approach

Before calculating collaboration intensity over time and their related costs, some basic assumptions have to be made:

- The definition of interactions within collaborative relationships is basically no problem.
- The interactions can be estimated in form, time, duration and intensity.
- In the period starting with $t_{0_{z_{ijk}}}$ and ending at $\left(t_{0_{z_{ijk}}} + t_{d_{z_{ijk}}}\right)$ the intensity of the interaction z_{ijk} is given by $x_{z_{ijk}} g_{z_{ijk}}$ at every point in time ($x_{z_{ijk}} g_{z_{ijk}}$ is constant during the duration).

The collaboration intensity of an interaction of category *k* at the point of time *t* is defined as

$$I_{z_{ijk}}(t) = \begin{cases} x_{z_{ijk}} g_{z_{ijk}} & , \; t_{0_{z_{ijk}}} \le t < (t_{0_{z_{ijk}}} + t_{d_{z_{ijk}}}) \\ 0 & , \text{ other cases} \end{cases}$$

The total collaboration intensity of category *k* at any point in time *t* can be formalised as the sum of the single collaboration intensities:

$$GI(t) = \sum_{i=1}^{N} \sum_{j=1}^{N} I_{z_{ijk}}(t)$$

The accumulated collaboration intensity of category *k* at point in time *t* yields to

$$AGI(t) = \int_0^t GI(t)\mathrm{d}t = \int_0^t \left(\sum_{i=1}^{N} \sum_{j=1}^{N} I_{z_{ijk}}(t) \right) \mathrm{d}t$$

The costs $c_{z_{ijk}}(t)$ of an interaction z_{ijk} at a point of time *t* can be calculated as

$$c_{z_{ijk}}(t) = \begin{cases} 0 & , \; t \le t_{0_{z_{ijk}}} \\ \dfrac{t - t_{0_{z_{ijk}}}}{t_{d_{z_{ijk}}}} C_{z_{ijk}} & , \; t_{0_{z_{ijk}}} < t < \left(t_{0_{z_{ijk}}} + t_{d_{z_{ijk}}}\right) \\ C_{z_{ijk}} & , \text{ other cases} \end{cases}$$

The accumulated costs at any point of time *t* are calculated as

$$AGC(t) = \sum_{i=1}^{N} \sum_{j=1}^{N} c_{z_{ijk}}(t)$$

Example: Given the collaborative network shown in Figure 3 four nodes are connected via edges (collaborative relationships). Node 1 and 3 are connected via a very intensive collaborative relationship. Node 3 and 4 are linked via an intensive relationship whereas node 2 and 3 are purely linked by a market transaction. The connection between node 2 and 4 is also weak.

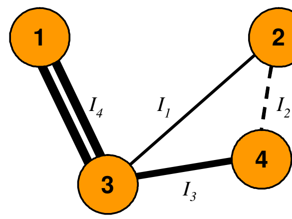

Figure 3: Exemplary network with 4 nodes

	$x_{z_{ijk}}$	$t_{0_{z_{ijk}}}$	$t_{d_{z_{ijk}}}$	$g_{z_{ijk}}$	$x_{z_{ijk}}\, g_{z_{ijk}}$
z_{13}	8.0	0	4	1.0	8.0
z_{23}	6.4	2	8	1.0	6.4
z_{24}	4.0	6	6	1.0	4.0
z_{34}	8.0	8	6	1.0	8.0

Table 2: Evaluated interaction

For this collaboration network, Table 2 shows the collaboration intensity $x_{z_{ijk}}$ for each interaction. Starting point and continuation as well as the weighting factor are defined for the timely aspects of the collaboration.
Figure 4 shows on the left side the collaboration intensity of single interactions over a time frame. The right side of Figure 4 shows the total collaboration intensity over time. This leads to a "row of houses" indicating the different intensities at different point of times. Finally, Figure 5 shows the accumulated collaboration intensities of the network over time.

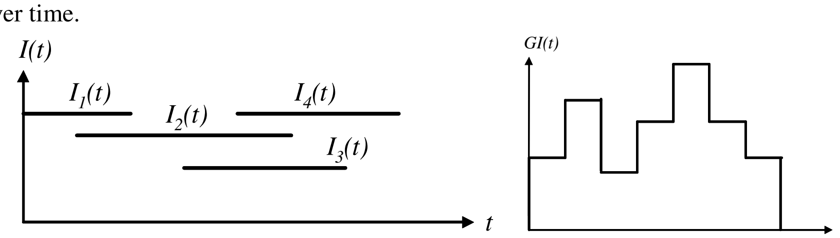

Figure 4: Collaboration intensities over time (left) and total collaboration intensity (right)

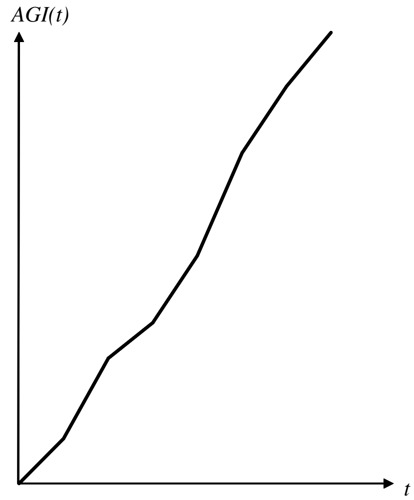

Figure 5: Representation of the accumulated collaboration intensity in a collaborative network

Summary and outlook

This paper has discussed how collaborative relationships can be analysed in Virtual Organisations. The results indicate that ideas from analysing networks can be used as conceptual basis to develop approaches for "organisational network analysis". The concept shows that five steps can be taken to achieve a more accurate information basis. This could provide a good basis for a better planning of the operation phase of Virtual Organisations.

The concept of collaboration intensity has been taken to try to adapt results from the social network analysis towards something the authors would call "organisational network analysis". This analysis is not based on the simple collection of quantitative data but more on the collection and interpretation of qualitative data. Here the issue of layman theories has been presented. Finally the "collaborative network relationship analysis" has been transferred in a mathematical model. As a conclusion mathematical model with an additional software tool is needed to have an information backbone for the significant number of interactions which need to be planned for distributed innovation processes within the operation phase of Virtual Organisations.

These results will be extended by a number of activities. First the mathematical model will be used in real case studies. Secondly it is planned to create an internet based software portal to be used for applying the methodology. Finally these results will be used to further update the general approach.

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