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Application of Social Network Analysis to study network evolution of collaborative networks

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Abstract

In order to solve so called 'wicked problems', more and more partnerships are set up fostering processes of collaboration and social learning in which actors with different organisational backgrounds: businesses, NGO's, universities and government agencies work together in creating new knowledge. Given the intrinsically relational nature of social learning in a complex environment, these partnerships can also be framed as a network: places where a broad range of participants generate new knowledge and subsequently distribute this over the participating partners and further beyond.

The aim of the paper is to present a mapping technique of social networks that can be used to aid in the study of the network dynamics of collaborative innovation networks. As people and organisations decide to enter or leave a partnership, the networks structure changes. This technique will be illustrated by constructing a longitudinal two-mode affiliation network over a period of 16 years. The analysis of the network dynamics shows how the structural characteristics of the network (size, composition, connectedness and centralisation) change over time. At the same time, the analysis can be used to investigate the micro level of the network and how some actors' positions within the network changes over time as they gain (or lose) influence. The paper ends with an exploration of other types of research questions that could be investigated using this method.

1. Introduction

The increasing complexity of western society has given rise to a special kind of societal problems known under different names as: wicked, messy, ill-defined or complex problems (Ackoff, 1974, Vennix, 1999, Hisschemoller and Hoppe, 2001). These problems are characterised by non-linear processes playing out on multiple levels involving a wide range of stakeholders with different views and interests. To deal with this type of complex problems, more and more partnerships are set up fostering processes of collaboration and social learning in which actors with different organisational backgrounds: businesses, NGO's, universities and government agencies work together in creating new knowledge. Given the intrinsically relational nature of social learning in a complex environment, these partnerships can also be framed as a network: places where a broad range of participants generate new knowledge and subsequently distribute this over the participating partners and further beyond (Van Bueren et al., 2003).

Social Network Analysis (SNA) offers a tool to systematically describe the structural properties of different networks. Currently social network analysis is dominated by network studies that explain the performance of either an individual or a company in terms of their position within this network (Borgatti and Foster, 2003). Networks themselves are either cohesive with many overlapping ties between the nodes or sparse with only few ties between the nodes and these structural characteristics influence the possibilities of the nodes for communication, development and exchange of new ideas (Meeus et al., 2008). However, this is only part of the whole picture. Paraphrasing Giddens (1984), one could speak of 'the duality of network structure': social networks are both the result of social interactions and reproduce these social interactions at the same time. This shifts the focus of the analysis from the influence network structure exerts on the individual to a more process-oriented view on networks (Gössling et al., 2007).

The issue how (changing) network structures are the result of individual behaviour has been raised mostly in the domain of physics, where the generation of large 'scale-less' networks (where the distribution of ties in the network follows a power law) are the result of processes of preferential attachment at the micro level (Barabási and Albert, 1999, Newman, 2003). Social scientists have called this preferential attachment mechanism 'rather simplistic' (Powell et al., 2005), but so far there has not been much work done on crossing the divide between the social and natural sciences use of network analysis (Borgatti et al., 2009). A first step towards this aim would be the study of longitudinal networks. However, these descriptions of longitudinal networks are still relatively rare. So rare in fact that Knoben et al. (2006) speak of a "longitudinal gap" that exists in the study of collaborative networks.

In this paper a method will be introduced that helps in mapping the network characteristics of a collaborative network over time in a relatively straightforward manner. As such it applies the concepts of network evolution to multi organisational partnerships and innovation networks. The field of network evolution studies emerging network properties at the macro level by investigating the decisions and actions at the micro level of the individual node (Stokman and Doreian, 1997). The paper starts with an investigation of the different levels of collaborative innovation networks: people, projects and organisations. As people and organisations decide to enter or leave a partnership, the networks structure changes and a new snapshot of the network structure has to be taken. This technique will be illustrated by constructing a longitudinal two-mode affiliation network over a period of 16 years. The paper ends with an exploration of other types of research questions that could be investigated using this method.

2. The micro and macro level of collaborative innovation networks

At the micro level, a collaborative network consists of the individual actors who work together in a multi-sectoral setting. Because wicked problems can't be solved by a single actor, different people are brought together each with his or her own specialism. Within collaborative projects, the actors can exchange information in a number of ways (Berends et al., 2006). However, one of the most important mechanisms is assumed to be the process of 'social learning'. Within a project the actors engage in a process of knowledge co-creation: new knowledge is created through conversations and interactions between actors from different backgrounds. Learning is therefore seen as a social process. New ideas are not necessarily the work of one brilliant individual. Instead, many new ideas come from applying existing ideas in a new social context, or by the recombination of existing ideas (Burt, 2005). Creativity and innovation are therefore stimulated by cooperation and active exchange of ideas. By bringing people together and giving them an opportunity to share their ideas and discuss them with other people, they align their personal mental models into a shared group model and as they learn from each other and form new relationships they develop the capacity to take collective action and manage their environment (Stringer et al., 2006, Armitage et al., 2008). Shared visions thus become an important driver for the process of innovation (Beers et al., 2010, Geels and Raven, 2006). This mechanism does not apply only to wicked problems, but also high tech innovation problems require more and more different types of specialists to be involved. Research in the field of biotechnology has shown that there is a trend towards more collaboration between a wider variety of actors. Over time the types of collaboration have shifted from mere commercialisation of research results, towards more collaboration between different actors in the research and innovation process itself (Powell et al., 2005).

In many multisectoral innovation projects, people do not participate individually, instead they represent a formal organisation: government, business, non-governmental organisations or research institutes. The macro level of the network structure is shaped by the formal relationships between the individual participants, the organisations they are affiliated with and different collaborative projects that are set up over time. This type of network can be represented using a 'two-mode affiliation network' depicting the relationship between the membership (or participation) of actors in a certain social event. A two-mode network thus contains two different types of nodes in the same graph called 'actors' and 'events'. The idea behind this type of network analysis is that the characteristics of a certain event can by studied by looking at the types of actors who participated on the one hand, while on the other hand it is possible to typify an actor by looking at his or her participation in certain types of events (Wasserman and Faust, 1994). Two-mode affiliation networks therefore allow us to study the different functions of the network on two different levels: that of the organisation (including the projects done) and that of the individual.

A collaborative innovation network can be conceptualised as a (small) network of organisations, enterprises and individuals that are linked together by a series of multidisciplinary collaborative projects that aims to bring new products, new processes and new forms of organisation into (economic) use. Figure 1 illustrates this with a hypothetical two-mode affiliation network that consists of 22 actors affiliated with 15 different organisations and 3 collaborative projects at time = t. The Figure shows how an individual actor is connected to different other individuals through his or her affiliation with an organisation or a project. The agency of the individual stems from his or her capacity to choose the organisations he or she is affiliated with and the social events (projects) that he or she participates in. On the other hand, the organisations and their internal rules, protocols and regulations, both formal and informal, pose restrictions on the behaviour of an individual. In Figure 1 all the actors only participate in a single project, with the exception of actor 6 who participated in 2 projects. However, organisations O and G have people representing them in two projects. Actors 13 and 22 belong to two different organisations (O and G for actor 13 and G and H for actor 22).

The network structure depends on the duration of the different projects. Not all projects start at the same time and some project take longer than other projects. Each network consists of a unique combination of projects and the people and their organisations that are affiliated with it. As a new project starts, new organisations and people enter the innovation network and once a project stops they leave again.

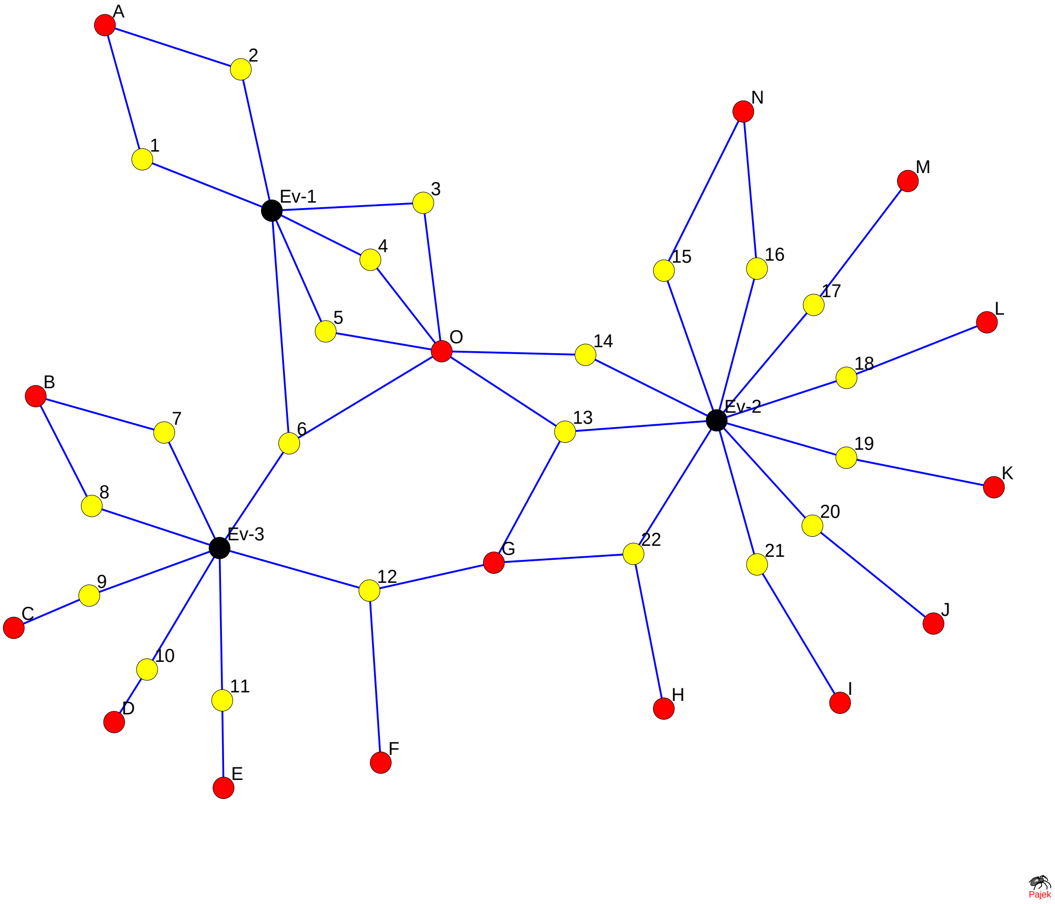

Figure 1: Hypothetical two-mode affiliation network at time = t; yellow nodes (numbered 1 to 22) represent people, red nodes (A through O) are organisations and black nodes are projects

3. Example of application: the Northern Frisian Woodlands

To explain the mapping method in more detail it is easiest to illustrate it with a concrete example, like the case of the Northern Frisian Woodlands. The Northern Frisian Woodlands is an area of about 60,000 ha located in the north of the Netherlands dominated by dairy farming. It consists of small-scale, closed landscapes on high sandy soils, alternated by relatively open areas on lower peat-clay soils. The small scale landscapes are formed by hedges and belts of alder trees surrounding the plots of land, resulting in a unique mosaic of parcels. In the 1990s, national regulations were drafted that imposed stringent measures to reduce the environmental impact of agricultural activities. This threatened the local farmers in their daily operations and as a response to this threat, regional environmental farmer cooperatives were established. VEL (*Landscape Association of Eastermar*) and VANLA *(Agrarian Nature and Landscape Association of Achtkarspelen)* were the first two environmental farmer cooperatives in the Netherlands with the aim to move towards viable and environmental friendly agro-systems attuned to the local landscape (Renting and Van Der Ploeg, 2001).

After their foundation in 1992, the cooperatives conducted a series of field experiments and collaborative projects together with a range of other actors: researchers mainly associated with different groups of Wageningen University and Research Centre (Wageningen UR, or WUR for short) but also civil servants, Non-Governmental Organisations, businesses and civil servants. They cooperated in a variety of (scientific) research projects that developed new knowledge on the best way to do landscape management and farm management using a system perspective of dairy farming that involved not only the cows and their manure, but also the grassland, the soils and the diets of the cows (Reijs et al., 2007, Groot et al., 2006, Van Apeldoorn et al., 2011).

The innovation processes and the environmental farmer cooperatives VEL and Vanla have been described extensively in terms of innovation and Strategic Niche Management (Wiskerke and Van Der Ploeg, 2004, Stuiver and Wiskerke, 2004, Stuiver, 2008), social learning (Eshuis and Stuiver, 2005), governance (Renting and Van Der Ploeg, 2001, Wiskerke et al., 2003) and interested readers are referred to these texts for more details.

3.1 Sources of data and data selection

Data were collected from the various experimental projects from the foundation of VEL and Vanla in 1992 until the end of 2008 using scientific descriptions of the projects, as well as archival information such as project proposals, final reports, minutes of various meetings, and an extended collection of over 220 newspaper clippings detailing the founding of the VEL-Vanla cooperatives between 1990 and the 2000. These newspaper clippings were further extended with a Lexis-Nexis search between the years: 2000-2010 on the topics of “NFW” and “VEL AND Vanla”. Information was structured using the timeline for the Northern Frisian Woodlands given by Van der Ploeg et al. (2007).

The selection of the projects included in the data set was limited to only those where members of VEL and Vanla participated, either through actively contributing or more passively by an advisory role or providing data for further analysis. Projects were categorised into four separate categories: 1) landscape management focussed specifically on payment schemes for the farmers to do the maintenance of the hedges and belts of alder trees themselves; 2) mineral projects focussed on the application of low external input farming on the dairy farms: managing the nutrient flows on their farms through a life cycle type of approach. The scientific projects (3) were used to study both the new practices of the farmers and deepen the life cycle perspective. The governance projects (4) were aimed at trying out new regional policy arrangements focussing on more self steering by the farmers. Interdepartmental working groups consisting of civil servants alone were not incorporated in the data set. Similarly, PhD research projects were not included. Selected projects were checked by two long time participants in the VEL-Vanla network for accuracy.

Details of the projects, such as the persons and organisations associated with them, their starting and end dates were recorded in a database. The starting and end dates were rounded to the nearest quarter as sometimes their start point of end point was not exactly clear. The network at any point in time is constructed through aggregation of all the projects that run on a specific point in time. Each network consists of a unique combination of projects and the people and their organisations that are affiliated with it. As a new project starts, new organisations and people enter the network and once a project stops they leave again. We can regard each of these network structures as snapshots of the project network at any given time, see Figure 2.

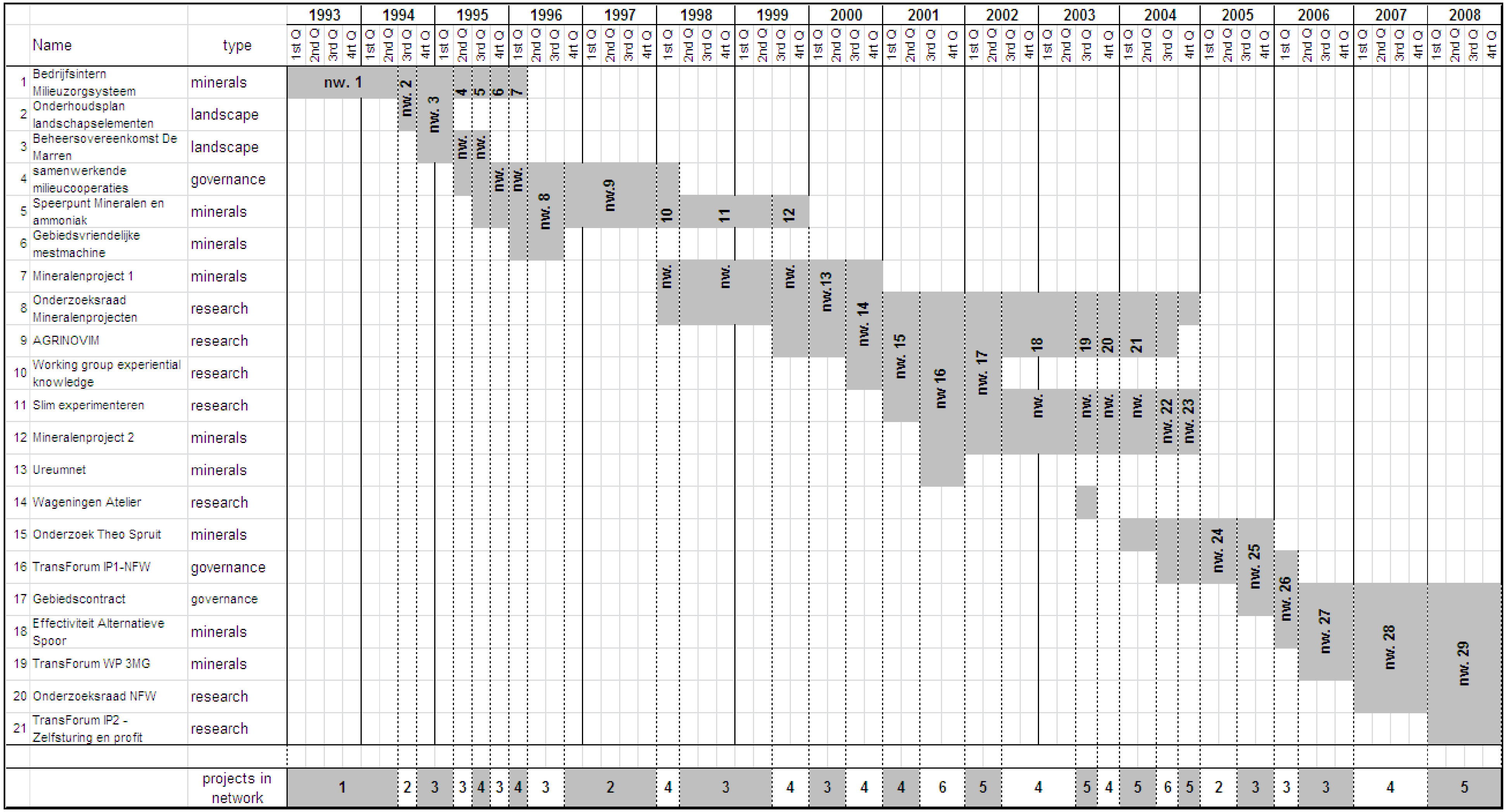

Figure 2: construction of networks through projects. The figure shows the different projects and their start and end dates. Each network is comprised of all the projects that are running at the same time. The bottom line of the figure gives the total amount of projects in each network and their duration.

Figure 2 illustrates how 29 different project networks could be identified, based on the combination of collaborative projects running at the same time. Playing these images quickly behind each other will eventually give a movie of the networks development over time (Moody et al., 2005). Space does not permit a full representation of all 29 networks, but Figure 3 depicts networks 1 and 16 as example. The first network shows the first project that was organised and how it brings ten persons from nine different organisations together. The other network, number 16, shows how six projects run during this period and how these projects are mutually linked through the persons that are member of the same projects. The complete set of networks has been visualised in a short movie that shows the growth of the network over time as well as the change in structure[1].

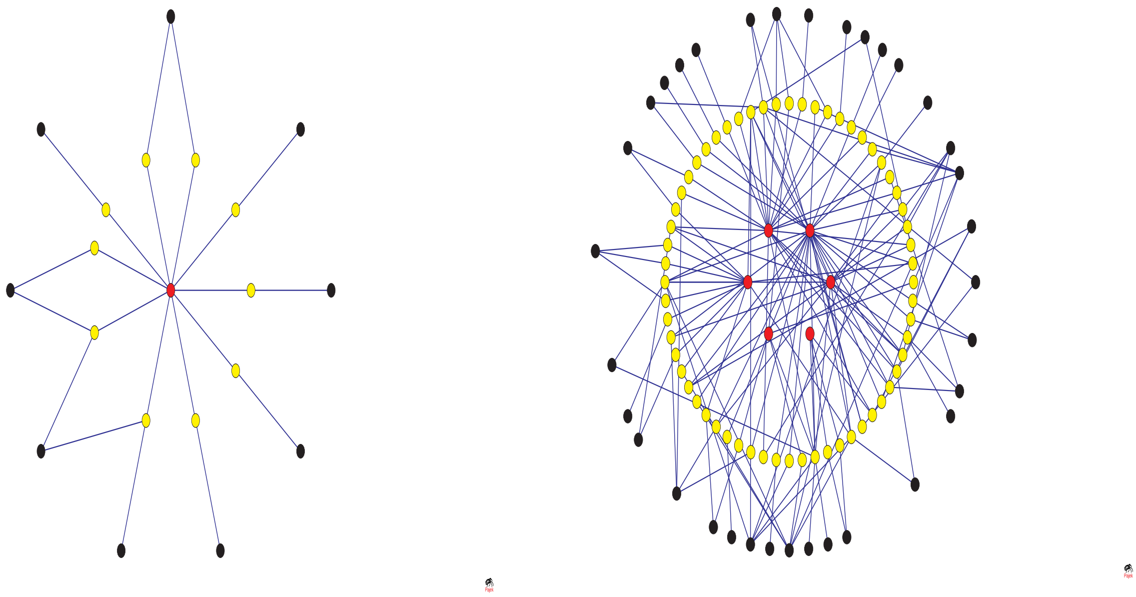

Figure 3: Project networks 1 and 16 (in January 1993 and October 2001 respectively), black nodes represent organisations, yellow nodes people and the red nodes denote projects

The structural properties of the networks were subsequently analysed using 'R' the statistical software programme (version 2.8.0) (R Development Core Team, 2008) and more specifically its statnet-package (version 2.1) (Handcock et al., 2003). Visualisation and was done using Pajek (version 1.26) (Batagelj and Mrvar, De Nooy et al., 2005) and SoNIA – Social Network Image Animator (Bender-DeMoll and McFarland, 2006).

[1] This movie can be found on youtube: http://www.youtube.com/watch?v=Z5yP_RkDHtY

4. Results

The graphs can be interpreted on two levels. The first level is that of the complete graph and its structural topology using ‘Graph Level Indicators’ like size, density, centralisation and composition to describe its properties. However there are two general problems when studying longitudinal two-mode networks. The first problem is that the analysis of the structural properties of two-mode networks is very difficult and some of the statistical techniques used for one-mode networks can’t be applied on two-mode networks. This problem is generally solved by using the one-mode projections of the networks, thus giving a network of the persons connected to each other and the networks of the organisations and projects connected to each other (De Nooy et al., 2005).

The second problem is one of the core problems of in longitudinal network studies and that is how to compare different sized networks with each other. Network size, density and centralisation are correlated, for which we have to control when interpreting the results. To circumvent this problem the mean degree of the nodes in the network can be selected as a measure for network density: that is the average amount of ties each of the nodes possesses in the network. This measure has the advantage that it is independent of network size (Stokman, 2001, Anderson et al., 1999). However this is not possible for some other network measures, like degree centralisation and betweeness centralisation (Freeman, 1979) connectedness and efficiency (Krackhardt, 1994). The Conditional Uniform Graph Hypothesis Test proposed by Anderson et al (1999) has to be used to estimate the effects of this possible interference.

Figure 4 gives an overview of the size and composition of time of the projected one-mode organisational network. Figure 5 gives an overview of the development of the projected one-mode graphs of the people within the network, their average number of ties per person (mean degree) and the degree centralisation of the network.

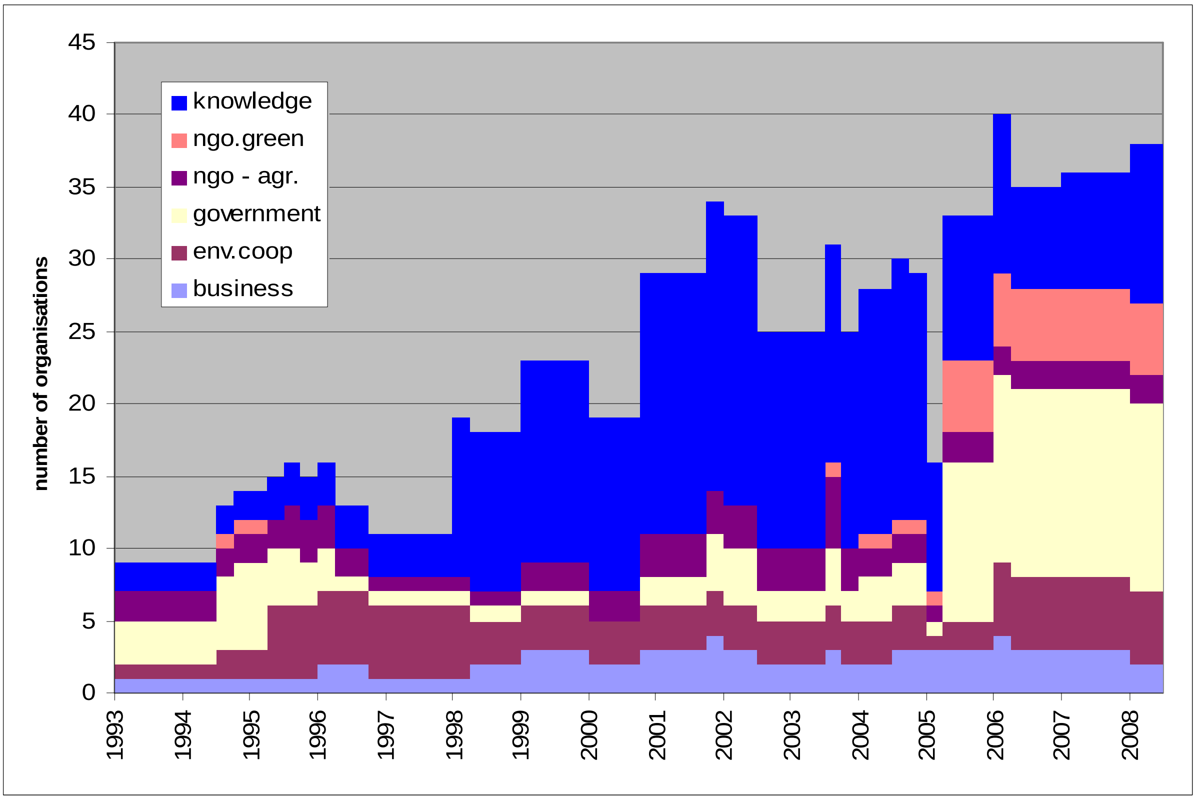

Figure 4: Network composition of type of organisation present

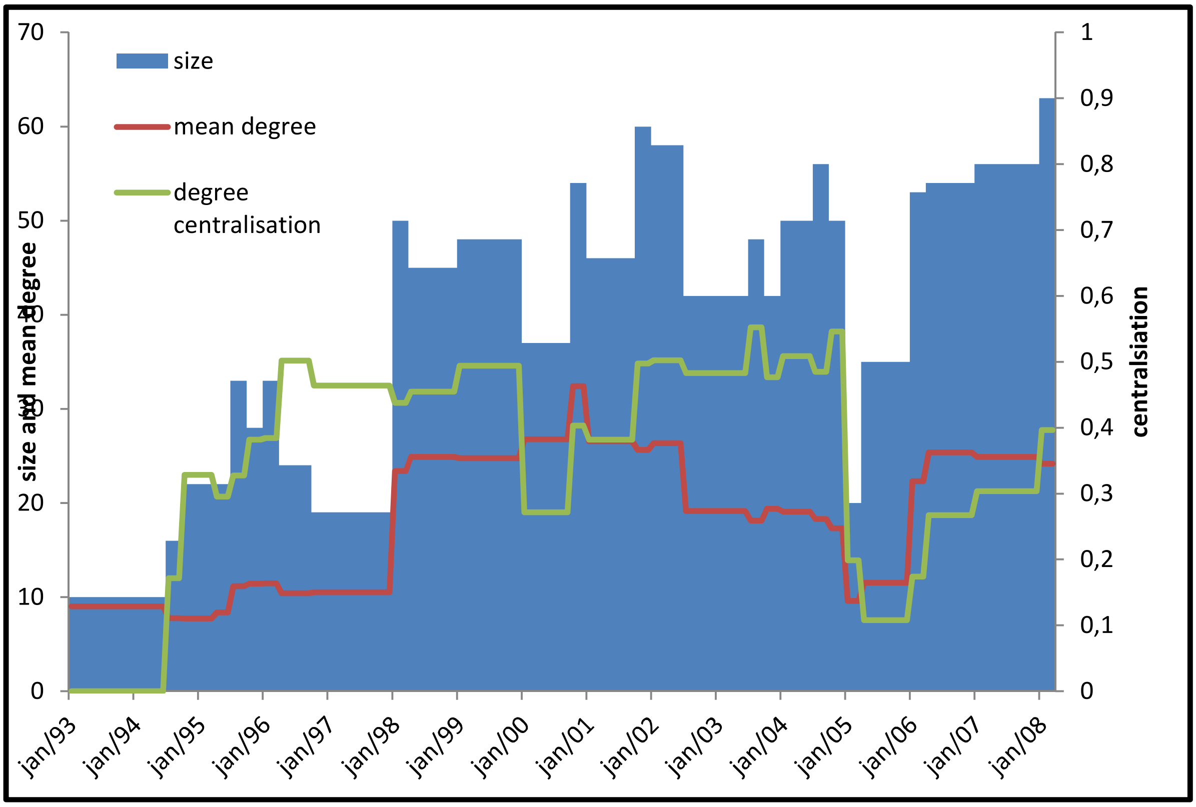

Figure 5: development of network size, average amount of ties per person and the centralisation of the network

The second level that can be studied is the level of the individual nodes. As the networks change over time, so will the positions of actors change within the network. Some will grow to prominence getting while other will fade to the background. A simple measure for the influence of certain people would be their participation rate within certain projects. The more projects people have participated in the more they can have their voices heard and the more they are able to steer the project in a desired direction. .

This is illustrated in Figures 6 and 7 where the individual degrees[2] of several actors in the projected one-mode networks are depicted. The two figures show that the chairman of VANLA was for a long time the most influential farmer within the network. Even after the merger of the two cooperatives VEL and Vanla into the new cooperation of the Northern Frisian Woodlands in 1998 he remained one of the central persons in the projects. It is only after the year 2005 the influence of the NFW board members starts to increase within the network. A similar analysis can be done for some of the researchers that participated in the different projects, see Figure 7. Their degree (and thus their influence) also fluctuates over time. The researcher from the rural sociology department was among the first to collaborate with the farmers. Later other groups joined as well and for a certain amount of time the researcher of the Animal Sciences Group was among the most connected within the network. However, as time progressed new thing were tried out and in the end the largest question remained on the role of the soil. In the last phase (after 2005) new research projects were defined that dealt specifically with the role of the soil and this explains the increase in the degree of the soil scientist.

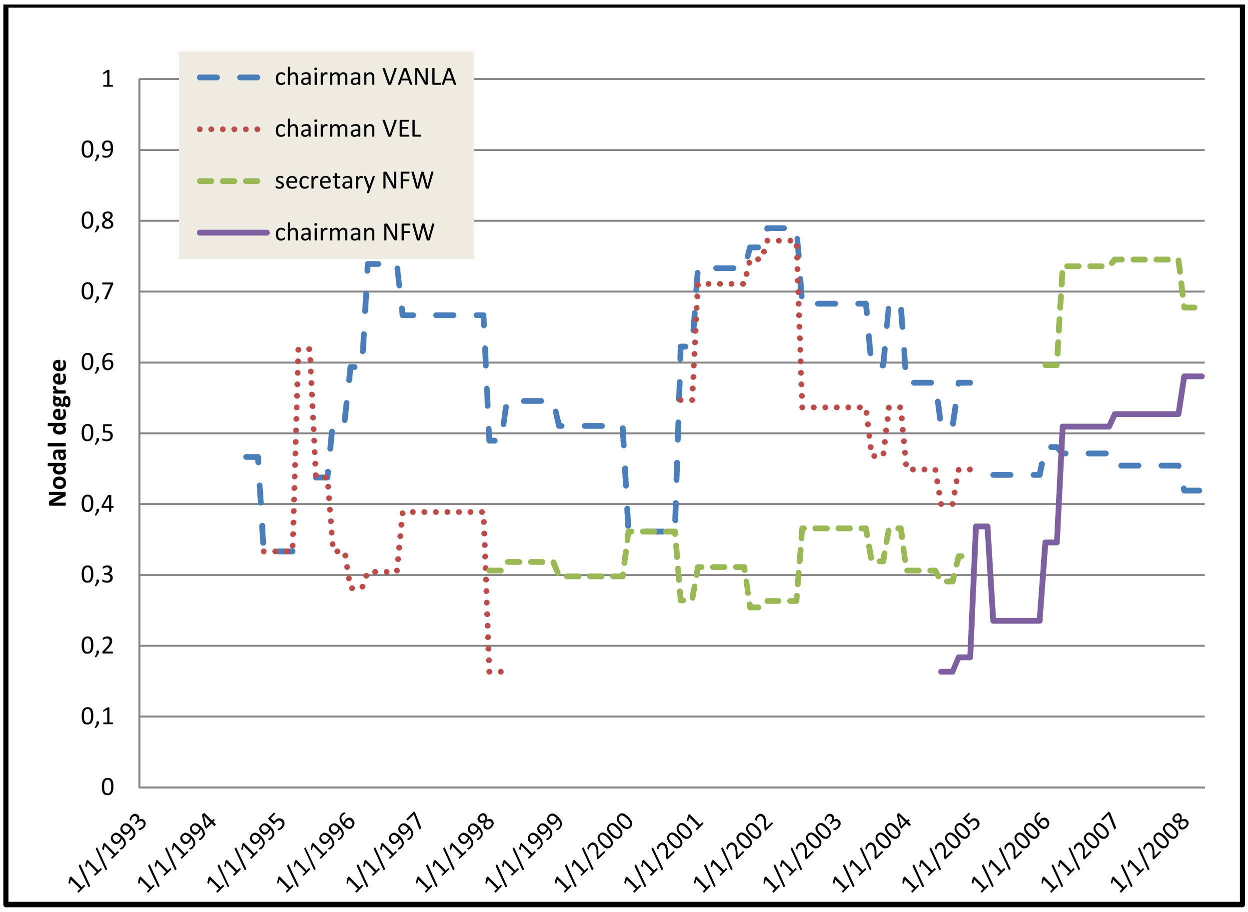

Figure 6: degrees of three farmers with a long term involvement in the projects of the NFW

[2] Calculated as a fraction of the amount of ties a node has (L_i) divided by the maximum amount of ties theoretically possible: $d_i = L_i/(G-1)$. Degrees thus have a range that fluctuates between 0 and 1.

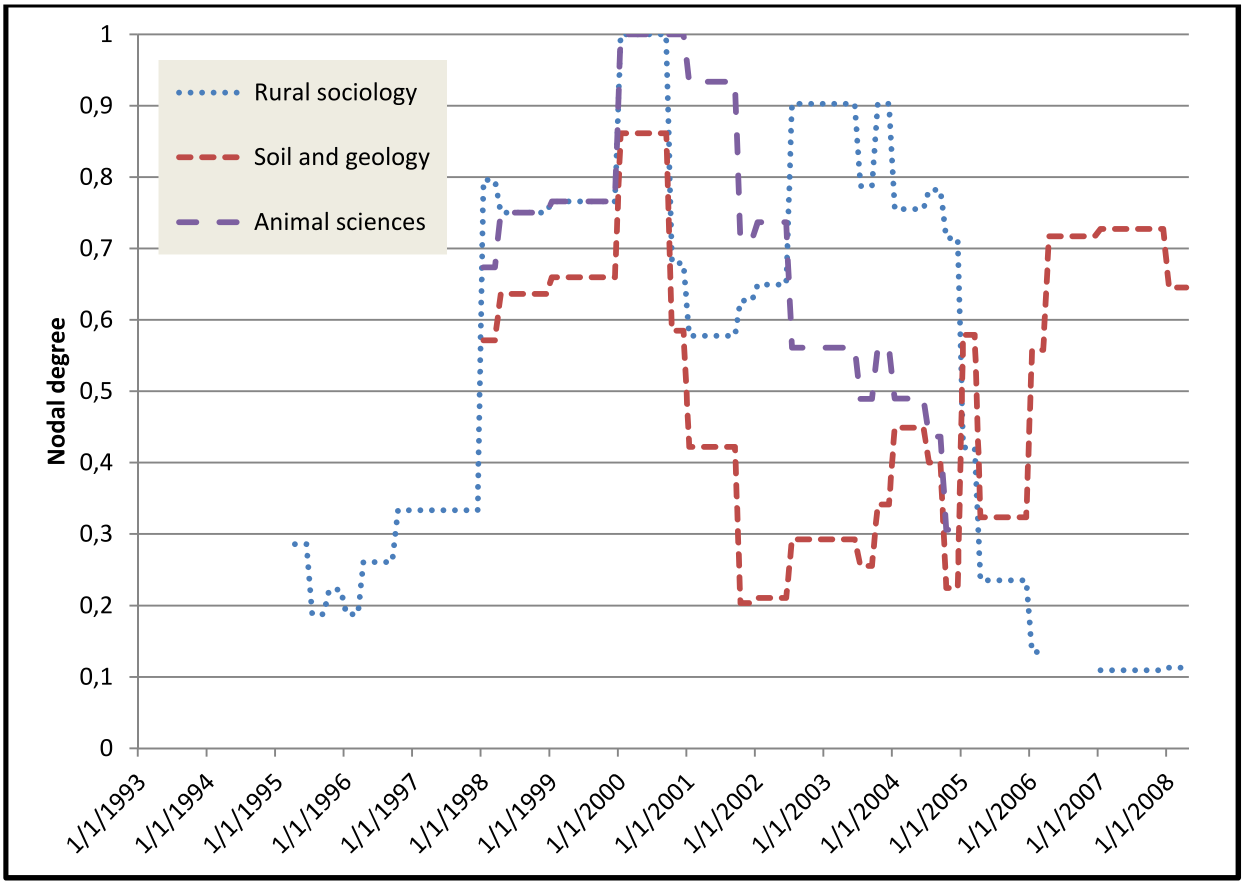

Figure 7: degrees of three scientists with a long-term involvement in the projects of the NFW

5. Discussion

The method presented constructs what Moody et al.(2005) have called discrete longitudinal network dynamics. It is important to note that this method to construct the networks holds an important assumption regarding the membership of people within a single project. The membership is assumed to be constant: no people leave or enter a project once it has started. It might be possible that a particular person of one organisation is replaced by another person as this does not fundamentally change the network structure. On the level of individual participants, most analyses will likely focus on the long-term participants of the network and the role they played over time. The assumption that they were a member over this period will hold up for this group and the error that results from this assumption is likely to be small. Using more detailed data could help to refine the method to also allow for the membership dynamics within a project, moving towards more continuous longitudinal network dynamics.

The application of the method in the case of the environmental cooperatives of the Northern Frisian Woodlands already gave some of the practical results the mapping of network configurations can result in, both at the level of the whole network (Graph Level Indicators) as well as on the level of individual nodes (participating farmers and scientists). With the availability of these simple network data it becomes possible to investigate more complex research questions, that are of interest for the study of multi-organisational partnerships and alliances. In this last section of the paper some examples will be given that deal with issues like social capital and trust, but also and network governance and the occurrence of typical network phases over time. Some of these issues require the availability of secondary data. In the case of the Northern Frisian

Woodlands these data were not always available, therefore we will just indicate some additional future work.

The first type of research question of such longitudinal network analysis focusses on the generation of social capital and trust that is often the result of collaborative partnerships. Social capital at the level of the complete network has been influenced heavily by the work of Putnam (2000) who has argued that more cohesive networks (networks with more affiliation tying the individual nodes together), also possess more social capital and in general will be better off. Figure 5 showed that network size and its mean degree display a strong correlation, indicating that a growing network will likely be more connected, inducing more trust between its members (Buskens, 1998). However there is likely a limit to this mechanism, because after the network has reached a certain size actors lose the overview of the whole network and the trust between its members is likely to go down.

The second application A related issue has to do with the management or the governance of the network. Successful network based collaborations tend to go from simple cooperation between independent partners, towards more integrated forms of collaboration where the innovation network becomes more centrally governed with the establishment of a central network steering body (Head, 2008). This would imply that also the networks centrality may increase over time. Although some trends towards more central steering of the network have been observed with the establishment of the research councils and the merger of VEL and Vanla into the Northern Frisian Woodland cooperation, Figure 5 does not reveal any clear pattern but future work could also look at different phases in the networks governance. Based on Figure 4 one could argue that the network shows three distinct 'waves': self-organisation and vision development between 1992 and 1998, testing this vision (1998-2005) and adaption of the original vision towards more regional development in the last phase (2005-2008). However other types of network phases are also possible. For instance, Rosenkopf and Tushman (1998) used survey data to mark different network phases related to the emergence of a dominant design, thus distinguishing between 'eras of incremental change' and 'eras of ferment' in technological. In a similar vein Soh and Roberts (2003) used the establishment of a dominant design in the ICT sector to designate three different phases, resulting in three separate networks that they analyse. However, both these studies have specified their network phases prior to the start of the network analysis. The mapping technique presented in this paper allows for more detail in the study of network phases because it does not require these phases to be defined beforehand but allows it to identify them from the network data themselves: the occurrence of the three waves suggest that the size of the network depends on the resources made available to it, and this mechanism might be explored with additional information on the monetary flows between project partners.

This provides a link to the study of the actions at the micro-level of the individual actors. Further research should focus on the process of attachment: who is involved in the definition of new projects and how are new partners sought? This is an important mechanism that shapes the network. Related to this question are the issues of the motivation of actors to join up and the change in their perspective along the way. With this type of information the distribution of costs and benefits at the individual level could be explored over time, and this would contribute to answering questions on the process of coalition formation and consensus building in networks. Each of the joining parties may have a different reason for joining the cooperation, while each also may have different resources in terms of finances, knowledge and power. During their cooperation visions may change as a result of the social learning mechanism, or as a result of the experiments and projects being done.

Conclusion

In order to study collaborative networks in more detail, social network analysis needs to move beyond the static explanations that currently dominate the literature and move towards studies of dynamic longitudinal networks. This paper has presented a simple, yet elegant, method to map the various network configurations over time by focussing on the flow of (multidisciplinary) innovation projects that are undertaken by a changing group of people. These projects form the glue of the network and are the places were actors interact, discuss and shape their ideas. As projects start or end, the network configuration changes. The resulting network dynamics shows how the different networks structures evolve over time. At the same time it shows the evolution of the ideas and areas of interest by identifying the main topics under investigation within the projects. Applying this method can help the study of multi-organisational partnerships, alliances and networks by investigating the development of trust and social capital, network phases and issues of coalition formation and consensus building.

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