INDIRECT TIES IN KNOWLEDGE NETWORKS: A SOCIAL NETWORK ANALYSIS WITH ORDERED WEIGHTED AVERAGING OPERATORS

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Doctor of Philosophy

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Thesis Summary

This PhD thesis analyses networks of knowledge flows, focusing on the role of indirect ties in the knowledge transfer, knowledge accumulation and knowledge creation process. It extends and improves existing methods for mapping networks of knowledge flows in two different applications and contributes to two stream of research.

To support the underlying idea of this thesis, which is finding an alternative method to rank indirect network ties to shed a new light on the dynamics of knowledge transfer, we apply Ordered Weighted Averaging (OWA) to two different network contexts. Knowledge flows in patent citation networks and a company supply chain network are analysed using Social Network Analysis (SNA) and the OWA operator. The OWA is used here for the first time (i) to rank indirect citations in patent networks, providing new insight into their role in transferring knowledge among network nodes; and to analyse a long chain of patent generations along 13 years; (ii) to rank indirect relations in a company supply chain network, to shed light on the role of indirectly connected individuals involved in the knowledge transfer and creation processes and to contribute to the literature on knowledge management in a supply chain. In doing so, indirect ties are measured and their role as means of knowledge transfer is shown. Thus, this thesis represents a first attempt to bridge the OWA and SNA fields and to show that the two methods can be used together to enrich the understanding of the role of indirectly connected nodes in a network. More specifically, the OWA scores enrich our understanding of knowledge evolution over time within complex networks. Future research can show the usefulness of OWA operator in different complex networks, such as the on-line social networks that consists of thousand of nodes.

Keywords: Indirect ties, knowledge flows, networks, Social Network Analysis, Ordered Weighted Averaging operator.

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I have been also tremendously fortunate to learn from my co supervisor Prof. John Edwards. His attention for details and for the overall picture has been a great help for me, and a great lesson about how to conduct research.

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List of abbreviations

SNA - Social Network Analysis

OWA - Ordered Weighted Averaging

SPLC - Search Path Link Count

SPNP - Search Path Node Pair

SPC - Search Path Count

CPM - Critical Path Method

EPO-PATSTAT - European Patent Office – Patent Statistical Database

IPC - International Patent Classification code

TQM - Total Quality Management

KSC - Knowledge Supply Chain

KSN - Knowledge Supply Network

SCN - Supply Chain Network

WoS - Web of Science

LP - Linear Programming

OWGA - Ordered Weighted Geometric Averaging

OWG - Ordered Weighted Geometric

MCDM - Multi-Criteria Decision Making

IOWA - Induced OWA Operators

IOWGA - Induced Ordered Weighted Geometric Averaging

ULOWA - Uncertain Linguistic Ordered Weighted Averaging

ULHA - Uncertain Linguistic Hybrid Aggregatio

FGHA - Fuzzy Generalized Hybrid Averaging

FIGHA - Fuzzy Induced Generalized Hybrid Averaging

IGOWA - Induced Generalized Ordered Weighted Averaging

OWAD - Ordered Weighted Averaging Distance

OWAAC - Ordered Weighted Averaging Adequacy Coefficient

FIGOWA - Fuzzy Induced Generalized Aggregation Operators

NP - Patent Network

Chapter 1. Introduction

In recent years *knowledge* has become an important topic for management and economic research (Hayek, 1945; Drucker, 1996; Foray, 2004). Starting from the development of the knowledge economy as an autonomous paradigm (Foray, 2004), many researchers have focused on measurement and investigation of the knowledge flows among firms, researchers and inventors. An important approach to the study of knowledge flows in a variety of contexts is Social Network Analysis (SNA) (Cantner and Graf, 2006; Allen et al., 2007; Barberá-Tomás et al., 2011; Martinelli, 2012; Cross et al., 2013; Epicoco, 2013), which has been used to map knowledge flows within communities of practice (CoP) (Allen et al., 2007; Louadi, 2008; Capece and Costa, 2009), and visualize knowledge diffusion in regional clusters using patent data, in order to understand the dynamics of technological relatedness and the knowledge space (Fontana et al., 2009; Kogler et al., 2013), and to analyse the development of disciplines and patterns of collaboration within a scientific field using paper citation networks (Barabási et al., 2002; Watts, 2003; Mina et al., 2007; Whitley and Galliers, 2007; Calero-Medina and Noyons, 2008).

Research aims and research questions

This thesis aims to investigate the dynamics of the processes of knowledge transfer, accumulation and creation using two different applications of SNA to map knowledge flows in patent citation and company supply chain networks. In so doing, differences between explicit knowledge, that embodied in a patent, and tacit knowledge, embodied in human relations, are considered (Polanyi, 1966; Nonaka and Takeuchi, 1995) and three research questions are addressed.

Patent citation data are used to analyse knowledge flows from a citation network perspective, focusing on explicit knowledge. The problems related to clear identification and measurement of these knowledge flows are partially overcome by use of patent data to proxy for knowledge flows (Griliches, 1992; Jaffe et al., 2000; Breschi and Lissoni, 2001; Duguet and MacGarvie, 2005; Criscuolo and Verspagen, 2008). These data are widely used to trace 'technological trajectories', to observe the knowledge production phenomenon within a discipline and to analyse collaboration among scientists. Another approach is to count direct citations which represent ties among patents. However, this method has some drawbacks. We know little about the role played by indirect ties among the nodes in a knowledge network. Knowledge passes among the nodes in a network, and indirect ties account for complex knowledge flows. Understanding the role of nodes within a complex network is difficult. Studying citation network helps to explain the dynamics of knowledge creation, and several methods have been proposed to identify the most important nodes and their contribution to the network. The first consists of analysing network node in-degree centrality, defined as the number of arcs arriving at a node, and out-degree centrality or the number of arcs departing from a node. In the case of patent citation networks, the in-degree centrality of node *i* is the number of patents citing *i*, and out-degree centrality is the number of citations by *i* to other patents. Other relevant algorithms include hubs and authorities, which allows identification of a citation network's most prominent vertices (Brandes and Willhalm, 2002; Batagelj and Cerinšek, 2013). Among existing work on citation networks, investigation of within-network indirect ties is limited. In this thesis, use of specific ordered weighted averages (OWA) based on the disparity model defined by Emrouznejad and Amin (2010) is proposed to assess the value of indirect ties. The family of OWA operators was first introduced by Yager (1988) as a tool to deal with the problem of aggregating multicriteria to form an overall decision function. He described this tool as consisting of cumulative operators for membership aggregation. There is a vast literature on OWA that includes several approaches to obtaining the associated weights. In this thesis, an alternative disparity model is proposed to identify the associated weights for SNA. To our knowledge, OWA based on the disparity model has not been used to analyse knowledge networks (citation networks or supply chain networks are the two types studied in this thesis). OWA has been used to preference ranking aggregations, and was developed in the context of web search engines. In the analysis of patent citation networks, this study employed OWA to analyse citations networks in order to allow decision making applications in this complex context. In the case of citation networks the decision-maker can be the network analyst or the policy maker interested in understanding the dynamics of specific patent citation networks. In the case analysed in this thesis, citation networks are composed of patents, which are the network nodes. In this context, this thesis investigates a somewhat underestimated research issue related to the role of indirect ties in complex citation networks. The research question addressed is what is the role of indirect ties in the processes of knowledge transfer, knowledge accumulation and knowledge creation within knowledge networks? We apply a disparity OWA operator to aggregate preference rankings with the results from SNA of the same knowledge networks. Two different types of knowledge networks are analysed, patent citation and supply chain. In the case of patent citations networks, this thesis aims to provide a ranking for a group of patents by considering indirect citations received along 13 years from their publication.

Studying the company supply chain network allows analysis of the knowledge-based relationships among the employees in a case study company, and the firm's knowledge relationships along the supply chain. The role of direct and indirect ties among employees is studied using OWA to complement the SNA application. In the company supply chain network, the decision maker may be the company management interested in understanding company knowledge dynamics. In the case studied in this research, the network is comprised of the employees in a small manufacturing company, with the ties in the network representing their direct and indirect knowledge relationships (or knowledge-based ties). Analysis of the knowledge transfer and creation process within companies and along companies' supply chains is a hot research topic (Gunasekaran and Ngai, 2007; Hult et al., 2007; Ketchen, et al., 2008). It is important to identify key knowledge assets in a knowledge-intensive supply chain (Hult et al., 2004, 2006; Ketchen & Hult, 2007; Ketchen et al., 2008) and to exploit this knowledge in an efficient manner (Desouza et al., 2003). Building on these studies, this thesis tries to identify the role of internal and external knowledge-based ties to improve the operational performance of organizations through better exploration and exploitation of individual and organizational knowledge. The related research questions are: How do organizations create new knowledge through their internal and external knowledge-based relationships? And, what is the impact on operational performance of managing knowledge-based ties? To address these research questions, this research first uses SNA to map the knowledge-based ties and. Second, we apply the OWA operator to rank the indirect knowledge-based relations, and to consider the role of indirect ties in the transfer of knowledge and the creation of new knowledge. Third, a qualitative investigation of the case-study company is conducted.

This thesis makes three main contributions to the literature. First, it is the first study to analyse the indirect ties in networks through the application of the OWA in two different research contexts to complement SNA. This application in the two types of networks leads to the second and third contributions.

The analysis of indirect citations in patent citation networks adds to our understanding of citation network dynamics by considering the role of the indirect ties among nodes, a somewhat overlooked issue in the literature. This thesis applies the OWA (originally developed in the context of web search engines) as an alternative method to analyse networks of knowledge flows, and to assess the role of indirect ties and reduce complexity for decision makers and analysts. This study provides evidence on the use of the OWA in decision making analysis in the complex context of large citation networks. More specifically, the thesis shows that the OWA operator provides measures of the cumulative inventive process by accounting for the diffusion of knowledge along several stages of the knowledge creation process. The measures provided explain how indirect citations to previous inventions reflect awareness of that knowledge in the specific knowledge context. For example, if an invention is not cited immediately, but does not disappear, it can take some time for subsequent inventors to acknowledge it. Within this perspective, investigating long citation chains using OWA will uncover more historical citations information.

The third contribution is the application of SNA and OWA to a supply chain context, to advance our understanding of the knowledge transfer and knowledge creation process along the supply chain. We demonstrate the usefulness of SNA for mapping knowledge flows in an organizational context and its enrichment through the application of OWA.

We identify the knowledge relationships, and individuals in the knowledge network, and describe the positive role of effective management of knowledge-based ties for the company's operational performance. The investigation of the role and management of the knowledge-based relations in a supply chain network contributes to the literature on knowledge management in a supply chain, which is the theoretical framework used to analyse the knowledge transfer and creation process in a supply chain context.

The conceptual development of this thesis is depicted in Figure 1.1.

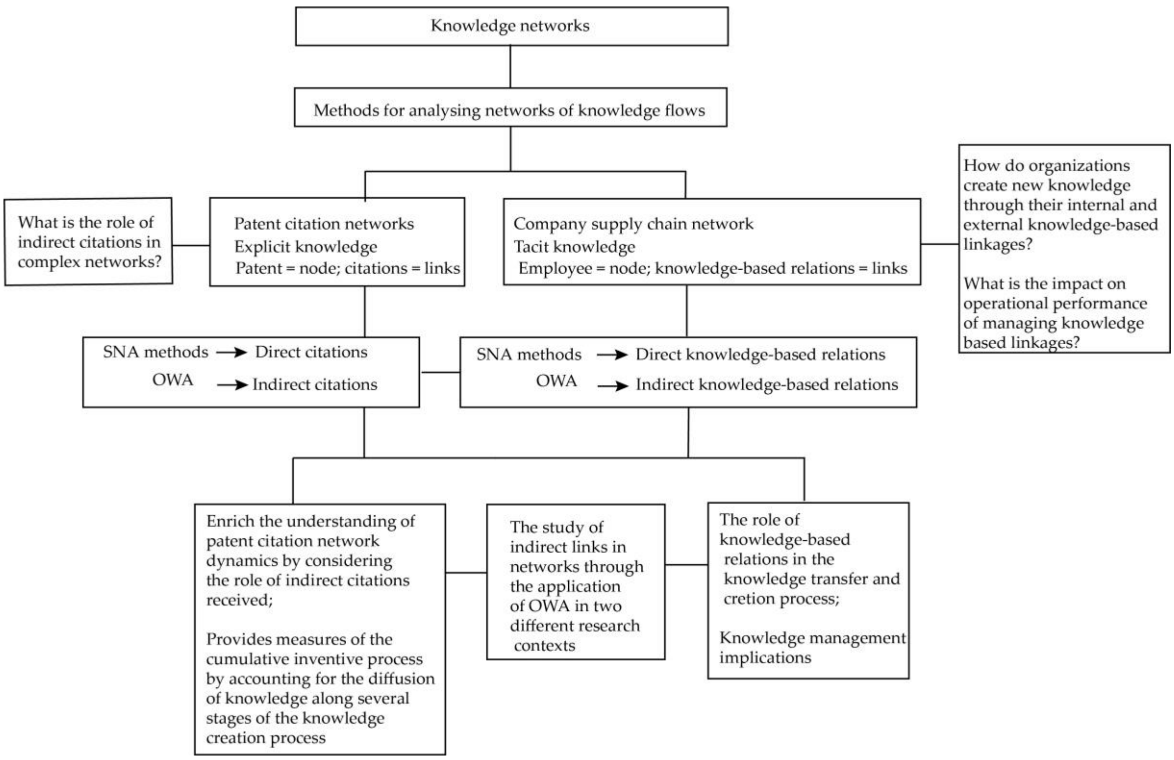

Figure 1.1. Conceptual development of the thesis

Chapter 2 introduces the main definitions related to networks, and introduces knowledge networks including citation and company supply chain networks. In the case of citation networks, we discuss *backward* and *forward* citations, and the significance of *direct* and *indirect* citations. Chapter 2 draws on work that uses patent data to investigate phenomena related to knowledge flows within a scientific field, describes the structural characteristics of citation networks and presents the main differences with respect of a company supply chain network. In the case of company supply chain networks, the focus is on the main issues related to supply chains and knowledge management literature; in these two research areas, the knowledge transfer and creation process is a hot topic. A version of the supply chain knowledge management literature review described in this chapter has been published in *Expert Systems with Applications*[1]. Chapter 2 shows how this thesis contributes to and extends this research area.

Chapter 3 provides a review of the literature on SNA methods used to analyse knowledge flows in the two network contexts (i.e. citation and supply chain networks). SNA is introduced and the main methods used to analyse knowledge networks and to map knowledge flows are presented. It highlights the underestimation of indirect ties, which represents a knowledge gap.

Chapter 4 presents the OWA method proposed to overcome the limitation identified in Chapter 3. A mapping of the literature on the OWA operator provides a detailed illustration to current OWA approaches. The disparity model developed by Emrouznejad and Amin (2010) is proposed for preference ranking aggregation; it is shown to be a useful method for decision making applications in complex contexts, such as citations networks with thousands of nodes, as well as smaller networks. A version of this chapter has been published the *International Journal of Intelligent Systems*[2].

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[1] Marra, M., Ho, W., Edwards, J.S. 2012 'Supply chain knowledge management: A literature review'. Expert Systems with Application, 39(5), 6103-6110. It can be downloaded here: http://www.sciencedirect.com/science/article/pii/S0957417411015788

[2] Emrouznejad, A., Marra, M. 2014. 'Ordered Weighted Averaging operators 1988-2014: A citation based literature survey'. International Journal of Intelligent Systems, 29(11), 994-1014. It can be downloaded here: http://onlinelibrary.wiley.com/doi/10.1002/int.21673/full

Chapter 5 presents the empirical analyses of patent citation networks. It described the unique dataset developed for this thesis. Compared to other available data, this dataset has specific and unique characteristics that stem from how the data were collected. The data source is the European Patent Office (EPO) Worldwide Patent Statistical Database (PATSTAT), which includes patents from 81 national and international patent offices, detailed information on patents published in the EU, and citations from EPO to non-EPO patents, that is, backward and forward citations to other world patents. The patents contained in the database are organized according to the International Patent Classification (IPC) system, developed by the World Intellectual Property Organization. This classification system is based on a hierarchy of codes structured at different levels. Following Johnstone et al. (2010), six IPC categories are used to identify the renewable energy sector (wind, solar, geothermal, ocean, biomass, waste). Data were collected iteratively, to identify forward citations to patents published in 2000, by patents published between 2000 and 2013, which yielded a total of 18,135 patents. SNA and OWA results are presented and the relation between the two is discussed. The results of the analyses are compared to show differences and similarities and to describe the usefulness of the OWA proposed in this thesis. A version of this chapter presenting the application of the proposed OWA to eight European patents has been submitted to *Information Sciences*.

Chapter 6 focuses on knowledge flows in the context of the company supply chain network. An empirical analysis is conducted using data collected on a manufacturing supplier company and its supply chain. The term ‘knowledge-based ties’ is used to highlight the tacit dimension of the knowledge affecting collaboration among different actors in the supply chain, with respect to the explicit dimension characterizing the networks studied in Chapter 5. In the case study in this thesis, classic SNA analysis is applied to identify the most important nodes in the knowledge network. OWA is applied to rank the relationships based on indirect ties. Qualitative methods consisting of in depth interviews, confirm that the nodes ranked using both SNA and OWA are also important for the effective management of the knowledge-based ties along the supply chain. A version of this chapter has been accepted for publication in *Knowledge Management Research and Practice*[3].

Chapter 7 presents the conclusions, limitations and suggestions for further work.

[3] Marra, M., Ho, W., Lee, C.K.M. Forthcoming. 'Managing supply chain knowledge-based linkages for improving operational performance'. Knowledge Management Research and Practice. It can be downloaded here: http://www.palgrave-journals.com/kmrp/journal/vaop/ncurrent/full/kmrp201428a.html

Chapter 2. Problem statement

2.1. Introduction and definitions

This thesis deals with networks and knowledge flows; we provide some definitions of the network concept and some of the terminology. A network consists of a graph which is as a set of *nodes* or *vertices* connected by *links* or *arcs* – these terms are used interchangeably in this thesis (Wasserman and Faust, 1994). Nodes can be persons, firms, papers, books or patents. Depending on the context, the network relationship (ties) can take different forms (Jackson, 2010) and terms such as 'knowledge networks' can be used to refer to the knowledge-based nature of the relations among nodes (Hansen, 2002; X. Liu et al., 2013); 'social networks' refers to networks whose nodes are individuals or organizations. The term 'social networks' refers to different kinds of networks. Examples of a social network can be friendship groups or business relationships involving different companies. There is no unique definition that differentiates types of networks, and sometimes terms overlap; a knowledge network can also be a social network. In this thesis the term knowledge network is used to describe the networks that are the object of study.

A network can assume the simplest form of a non-directed graph, in which two nodes are connected or not. In such simple networks ties show no directionality, so there is no differentiation between the directions of ties (left side of Figure 2.1.) (Medhi, 2010). In directed networks we know the directionality of the ties (right side of Figure 2.1). Undirected networks, such as family networks, imply the concept of 'mutual consent', which means that nodes are connected to each other, but it is not possible for one node to be related to a second node without the second node being related to the first node. Many social and economic networks, such as business partnerships, alliance networks and acquaintance networks are characterized by mutual consent. In contrast, a directed network, such as one that tracks which authors reference which other authors, or networks among web sites, do not need mutual consent (Jackson, 2010). This thesis focuses on this second type of network.

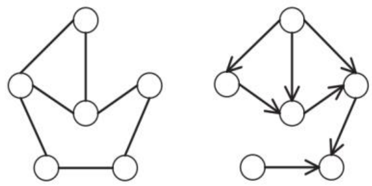

Figure 2.1. Undirected network (left) and directed network (right)

SNA has been applied widely to investigate several types of networks and relationships; for example, workplace friendship networks (Cross and Parker, 2004); networks based on family ties (Shor et al., 2013); economic networks (Jackson, 2010; Graham, 2015) networks of competitors (Lomi and Pallotti, 2012); networks of organizational communities in the context of manufacturing relations (Lomi and Pattison, 2006); knowledge networks within multinational corporations (Hansen, 2002); networks of academics (Jarvey et al., 2012); networks of institutional collaboration (D' Amore et al., 2010); informal relations among members of a company (Allen et al., 2007); inter-organizational networks of scientists and innovators (Cantner and Graf, 2006); co-authorship networks (De Stefano et al., 2011); citations (Pilkington and Meredith, 2009); and technology-based networks (Jaffe et al., 1998; Barberá-Tomás et al., 2011). Thus, the study of networks can adopt different perspectives and diverse theoretical frameworks. This thesis focuses on two types of networks and their knowledge-based relations: patent citation networks and supply chain networks. Both are examples of knowledge networks.

2.2. Knowledge networks

The term 'knowledge networks' is used in the literature to denote a set of nodes and their knowledge relationships. In a knowledge network, nodes represent knowledge units - they may be books, papers, patents, scientists or employees, and ties indicate the knowledge-based relations between nodes (X. Liu et al., 2013). In each case, we can construct a graph N = (U, R) where U is a set of vertices and R is a set of arcs. This thesis assumes that knowledge passes from one node to another and that indirect ties can be vehicles for knowledge transfer.

Citation networks and supply chain networks are examples of knowledge networks since they are composed of relationships among knowledge sources. Citation networks have specific characteristics that need to be described before specifying a method to analyse the networks of knowledge flows.

Supply chain networks do not show these characteristics, but can be considered an example of a directed network, where nodes are employees and organizations along the supply chain.

2.3 Citation networks

Citation networks can be based on patent citations or academic paper citations. The following condition describes a citation network: the arc (u, v) goes from vertex $u \in U$ to vertex $v \in U$ if the patent (u) cites the patent (v). This citing relation is defined as follows: $uRv \equiv u$ cites $v \equiv v$ is cited $by\ u$.

The arrow represents the flow of knowledge from a node or patent to another node or patent, and can be depicted as follows:

Figure 2.2. Example of a citation network

Although in this thesis the focus is on patent citation networks, there are some relevant differences between papers and patents. Both types of documents contain citations to previous work; patents contain citations to previous patents and the scientific literature, papers contain citations to previous papers or books. Academic paper references are not strictly recognition of previous relevant knowledge; academic authors may cite previous works for strategic reasons, such as the author of the cited works being a journal referee (Criscuolo and Verspagen, 2008). Recent studies show that, despite some limitations, patent citations can be considered a good measure of knowledge transfer since they reflect some kind of knowledge spillover (Jaffe et al., 2000) and are correlated significantly with the way firms acquire and disseminate knowledge (Duguet and MacGarvie, 2005).

A patent is a detailed document and a set of exclusionary rights granted by a state to an inventor or assignee. A patent document includes, amongst other information, references to previous patents and to the scientific literature. Patent references perform a specific legal function and obey a different rule from references to journal articles. Journal article citations are introduced only by the article's author(s); patent citations are inserted by both patent applicant (inventor) and the patent examiner.

Study of citation networks originates in bibliometrics, which can be defined as 'the assembling and interpretation of statistics relating to books and periodicals…to demonstrate historical movements to determine the national or universal research use of books and journals, and to ascertain in many local situations the general use of books and journals' (Raising, 1962, p. 348). This field has increased over the last few decades boosted by advances in information technology, which have allowed faster and massive digitalization of written documents. Interest in different network measures (Newman, 2001; Karrer and Newman, 2009; Radicchi et al., 2012) has increased because of their impact on our understanding of the knowledge diffusion process in relation to disciplines (in the case of academic citation networks) and technological innovations (in the case of patent citation networks).

Citation networks have some important features, such as the relation between the number of citations and time, which affect their study. For example, the number of citations a node (paper or patent) receives, decreases over time, and the number of citations to a given node is considered an estimate of its relevance and prestige within the network. Studies using SNA to analyse citation networks, analyse network centrality by considering direct ties (Whitley and Galliers, 2007; Chang et al., 2009). Network centrality measures the number of each node's connections, and uses the number of ties to assess the importance of the network node (Borgatti and Everett, 2006). The higher the number of direct citations received by a patent/paper, the higher its importance in the knowledge flows of the network. Other researchers have suggested specific algorithms to map citation networks and understand the knowledge flows across them (Batagelj, 2003; Batagelj and Cerinšek, 2013). Chapter 3 discusses these methods.

Patent citations count, that is, the count of direct citations received by a patent, are widely used (Trajtenberg, 1990; Henderson et al., 1998; Jaffe and Trajtenberg, 2002; Branstetter and Ogura, 2005; Duguet and MacGarvie, 2005; Hall et al., 2005). Gambardella et al. (2008) use patent citations to measure value; Duguet and MacGarvie (2005) assess the legitimacy of using patent citations to measure technology flows. However, the meaningfulness of patent citations count has been questioned. Several scholars have questioned the value of considering only the number of direct citations to assess the importance of a patent in a citations network (Harhoff et al., 2005; Gambardella et al., 2008; Bessen, 2009). Several authors have expressed similar concerns in relation to paper citations networks. Hirsch (2005) and Garfield (1973) discuss the inadequacy of considering only citations count to assess the importance of a scientific achievement. Radicchi et al. (2008) state that a simple count of the number of citations received by a paper is misleading to evaluate its scientific value, and to compare papers in different disciplines since the chances of a publication being cited can depend on the category to which it belongs. Jarvey et al. (2012) point out that citation counts cannot indicate the importance of the authors' paper; the prestige of the journal publishing the article or cited by the article; or whether citations are simply due to a longer publication history.

In this thesis, the focus is on patent (not paper) citation networks, and patent citations are considered a proxy for knowledge flows and diffusion. We argue that indirect citations in a network should also be considered vehicles for knowledge flows. It is acknowledged that knowledge can flow from one node to another, so the influence of previous nodes on a citation path needs to be considered when trying to understand the importance of a citation network's nodes. In SNA, closeness centrality measures the role of indirect ties. However, closeness centrality is generally not computed for citation networks, which usually are not strongly connected networks, that is, there are no direct paths between node pairs.

2.4 Structural characteristics of citation networks

2.4.1. Citations distribution

In trying to understand the importance of network citations, it is necessary to consider their distribution. Some studies highlight some of the structural features of citation networks. These studies mostly focus on paper citation networks. However, similarities between paper and patent citation networks have been highlighted (Mina et al., 2007; Verspagen, 2007), such as the properties of directionality and acyclicity (discussed in the next section). Table 2.1 summarizes these studies.

Some studies highlight the structural features of citation networks, focusing on the probability distribution function of citations, that is, the probability $P(k^{in})$ that a publication has been cited k^{in} times. Price (1965) proposes a power law scaling $P(K^{in}) \sim (K^{in})^{-\gamma}$ with a decaying exponent $\gamma \simeq 3$, and Price (1979) theorizes the so-called cumulative advantage mechanism, which refers to the situation in which success breeds success. Redner (1998) and Seglen (1992) show that distributions of article citations are very skewed and confirm power law scaling using a much larger dataset. Others have produced different findings. For instance, Laherrère and Sornette (1998) employ a dataset of the top 1,120 most cited physicists between 1981-1997, and find that the whole distribution of citations is stretched exponential $P(K^{in}) \sim \exp\left[\left(K^{in}\right)^{b} \right]$ with $\beta \simeq 0.3$.

Redner (2005) analysed all papers published in the 110-year history of the *Physical Review* and found that the distribution of citations is best fitted by a log-normal distribution.

The lack of consensus seems to be due to different potential biases, for example, the particular dataset considered, or lack of consideration for possible discipline or age-dependence statistics (Radicchi et al., 2012).

Table 2.1. Citations distribution characteristics

Citations distribution characteristics	**Authors**
Power-laws	Price (1965); Seglen (1992); Vazquez (2001); Lehmann et al. (2003); Bommarito and Katz (2009); Redner (1998); Eom and Fortunato (2011)
Log-normals	Radicchi et al. (2008); Castellano and Radicchi (2009); Stringer et al. (2010).
Tsallis distributions	Wallace et al. (2009); Anastasiadis et al. (2009)
Modified Bessel functions	van Raan (2001a, 2001b)

2.4.2. Discipline and age dependence

Publications in certain fields are cited much more or much less than in others. Discipline related factors also matter; papers in sectors such as mathematics follow different citing behaviour from those in biology. Factors affecting this phenomenon are:

- uneven number of cited papers per article in different fields;
- unbalanced cross-discipline citations (Althouse et al., 2009); there is a difference between the impact factors for mathematics and medicine. The highest 2006 impact factor for journals in mathematics is ten time lower than that in medicine related journals (Garfield and Merton, 1979);
- differences in citation practices (Moed et al., 1985);
- differences in the lag between publication and subsequent citation (Marton, 1985);
- the average number of authors per paper;

- the role of time, which is important - the number of papers published per year increases exponentially (Price, 1975) and the publication time for modern journals has become faster. The age of a paper is an important factor, it has been suggested that older literature is cited less than newer papers (Marton, 1985); but it can be argued that if the dataset includes papers published in different years, older papers will tend to have more citations than more recent ones, just as a function of their longer exposure. The potential obsolescence factor interacts with the discipline related factor as some disciplines grow and publish at a faster pace. Radicchi et al. (2008) analyse the distributions of citations received by a single publication, across several disciplines, rescaled on a universal curve. They introduce an unbiased relative indicator c_f of scientific impact, for comparison across disciplines and years. They show that large variability in the number of bare citations c is fully accounted for when $c_f = {}^{c}/_{c_o}$, where c_o is the average number of citations per article for the discipline, is considered. Using this unbiased indicator, a 'universal behaviour', that resembles a log-normal distribution, occurs when citation distributions of articles published in the same field, but in different years, are compared. Although both phenomena can occur according to the datasets and time window considered, a recent study finds that citation dynamics is characterised by bursts occurring within a few years from publication (Eom and Fortunato, 2011). They investigated data for papers published in the Journals of the American Physical Society and found that a shifted power law is the most reliable hypothesis for all citation networks derived in the dataset.

Citation networks usually have the following characteristics:

- *backward* and *forward* citations, the first refers to citations to other documents, while forward citations are citations received from other documents published at a later time; in Figure 2.3 the citation 'DA' is a backward citation made by D to A; and a forward citation received by A from D;
- *acyclicity* which refers to the time dimension - it means that the patent can be cited only by forward patents;
- *directionality* which refers to the direction of ties;
- *irreflexivity* which means no patent can cite itself;
- *direct and indirect ties.*

These properties are displayed in Figure 2.3, which shows the forward citations received by A. Let A be a patent published in 2000 and B, D and F be patents published around 2006 and citing A. The ties between A and B, A and D, and A and F are direct citations. If C cites B without citing A this is an indirect citation. C also cites D, indicated by the grey line, which means that, although it might appear to be another indirect citation it is not considered as such because of the previous direct relation between D and A. In other words, since there are two or more indirect citations, but all refer to the same original node, they are counted only once. While it is straightforward to identify direct citations, indirect citations require that each node in the network is counted only once and, more specifically, on first appearance. Figure 2.4 depicts the same concept in a more intuitive manner. The nodes in the diagram that appear more than once are counted only at their first appearance in time; subsequent appearances of the same node are coloured grey to indicate that they have not been counted. 1st place refers to direct citations, 2nd 3rd 4th and so on refers to indirect citations. Thus, if the same node appears in both first and second place (such as node D in Figure 2.4), it is considered only in the first. If the same node appears twice within the same place (node I) it is considered only once. Note that, in this thesis, 'place' refer to the direct and indirect ties (i.e. direct and indirect citations in a patent citation network, direct and indirect relation in a company supply chain network)

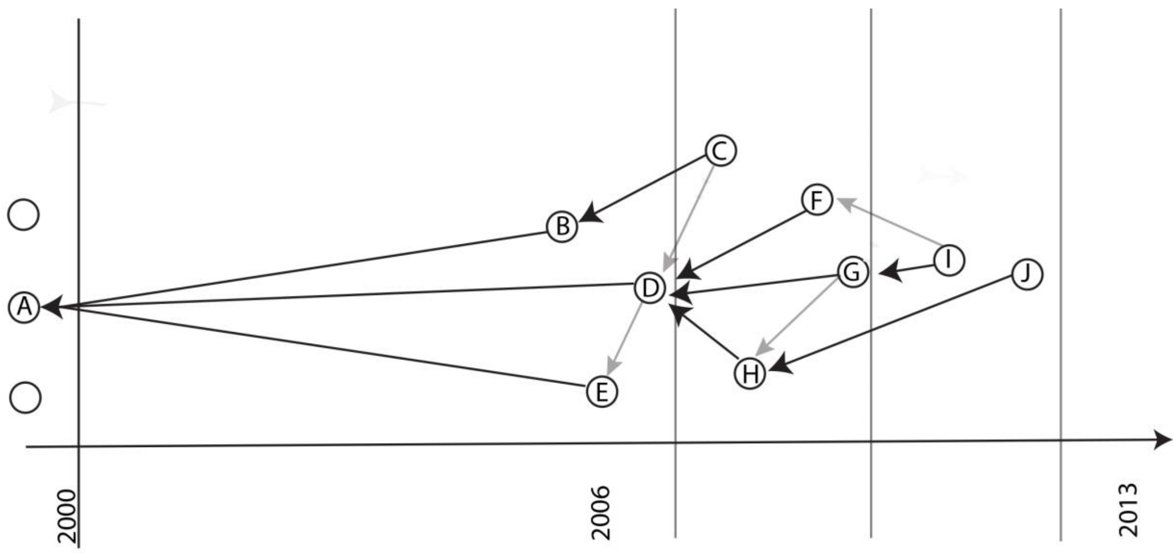

Figure 2.3. Example of a citation network with direct and indirect citation

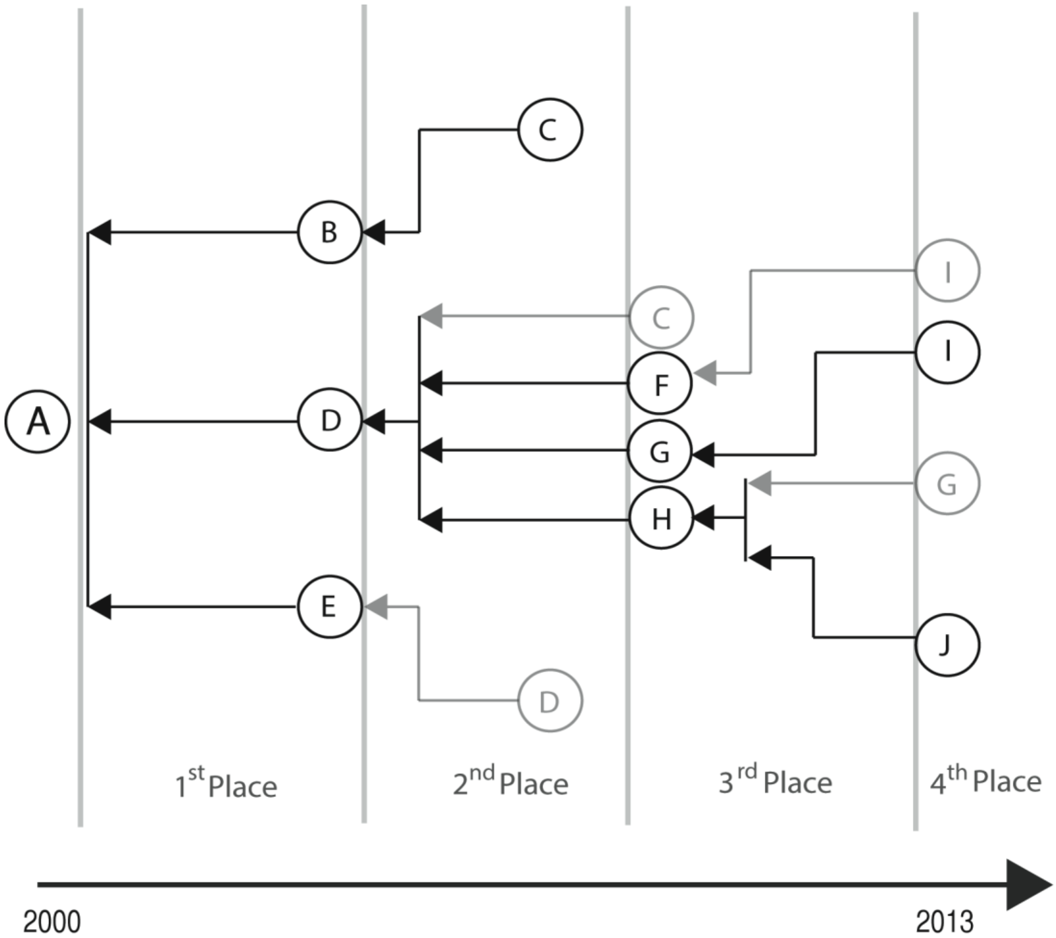

Figure 2.4. Logical structure of indirect citations

In the present study, patent citations are considered proxies for knowledge flows, which is in line with other studies (Jaffe et al., 2000; Acs et al., 2002; Duguet and MacGarvie, 2005; Peri, 2005; Criscuolo and Verspagen, 2008; Chang et al., 2009). Patents are considered an (imperfect) measure of (but a good proxy for) technological innovation (Johnstone et al., 2010) and an incomplete measure of (but a good proxy for) knowledge flows (Criscuolo and Verspagen, 2008). In fact, they capture only those flows that result in novel and patentable technology. Acs et al. (2002) endorse the appropriateness of both patent and innovation counts as reliable measures of knowledge production.

This thesis tries to overcome some of the limitations of existing work by:

- ranking patent citations using OWA (Emrouznejad and Amin, 2010), with the aim of obtaining a score that explains the longevity of patents over time. This approach provides a better explanation of patent success than SNA analysis on its own. The basic idea is that the diffusion process in directed networks can be explained better by considering the indirect citations received over time than by relying on purely local measures such as citation counts. In fact, analysis of indirect ties sheds light on otherwise underestimated aspects. Information and knowledge can flow between the nodes in a network.

2.5. Company supply chain network

In contrast to what was described in the previous paragraphs, a network involving a supply chain, composed of people and other organizations, such as business partners and research institutions, does not show similar structural characteristics to those described for citation networks. This second type of networks does not experience the constraints described for citation networks, specifically the time dimension is not considered. In Figure 2.5 we re-draw Figure 2.3 removing the time dimension (2000-2013), to provide a depiction of a network in which the nodes are people not patents. Given this difference, in a company supply chain network flows of knowledge can be in both directions. Figure 2.5 shows that knowledge can flow from A to B and B to A, that is, A nominates B as its source of knowledge and B nominates A as its source of knowledge, or that A and B collaborate to solve a problem. This condition is called *reciprocity*. Indirect relations are counted in a similar way, that is, if a node C cites two other nodes, B and D, both connected to A, we do not count both indirect citations to A.

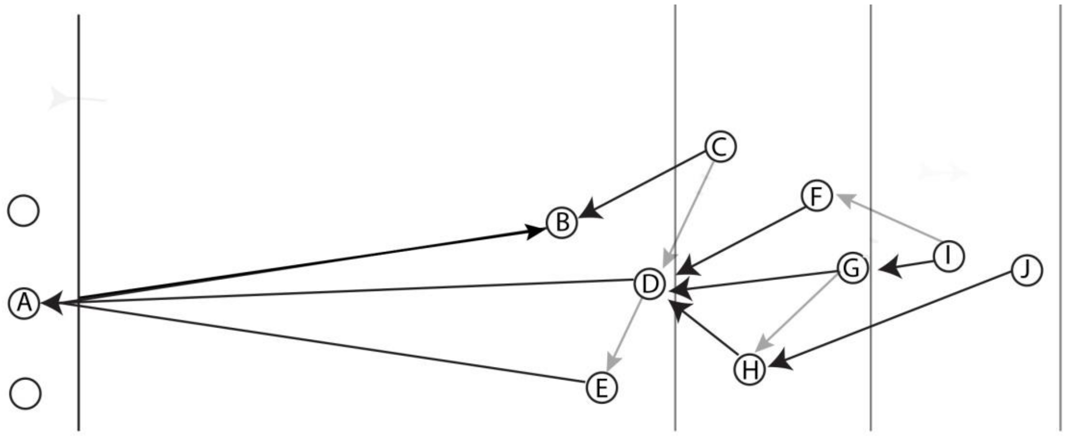

Figure 2.5. Example of supply chain network and reciprocity

However, supply chain networks are difficult contexts for the study of knowledge flows. First, the type of knowledge transferred in such network is mainly tacit. This means it is difficult to transmit or transfer to others. This kind of knowledge is extremely context bound: it is embedded in the individuals or groups that create it and it is difficult to separate from the human actors. For this reason, tacit knowledge is not easily transmitted through formal ties and codified communication. The tacit dimension of knowledge makes it transferable only via observation and imitation (Nonaka and Takeuchi, 1995). This kind of knowledge is a crucial asset for the firm's competitive advantage and is a firm-specific resource, which explains why the knowledge transfer process in supply chain networks is inevitably affected by problems of knowledge dispersion, knowledge obsolescence and knowledge integration. Second, since it is not transmitted by formal ties, informal relationships among the organizations have to be studied and mapped. SNA is an attractive tool for management scholars because of its ability to map informal relations among people (Wasserman and Faust, 1994; Allen et al., 2007). According to Borgatti and Li (2009), adoption of SNA in a supply chain context is useful to investigate phenomena related to the knowledge transfer process, and to understand behavioural mechanisms in supply chain networks. Along these lines, Louadi (2008) proposes SNA to study knowledge flows across multiple organizational units. Some studies adopt SNA to map:

- information-based links (Barratt and Barratt, 2011);
- flows of material along a supply chain (Capó-Vicedo et al., 2011);
- informal relations, such as friendship, or spontaneous collaboration among employees (Allen et al., 2007);
- to measure knowledge creation in virtual teams (Capece and Costa, 2009).

We investigate the methodological aspects of these studies in Chapter 3.

The growing importance of managing and measuring knowledge flows along a supply chain is also signalled by the recurrent use of terms such as 'knowledge supply chain' (KSC) (Choi et al., 2004; Cha et al., 2008) 'knowledge supply network' (KSN) (Pedroso and Nakano, 2009; Xiwei et al., 2010), and 'supply chain network' (SCN) (Halley et al., 2010), which respond to the need to view firms and their entire supply chain as a network capturing knowledge flows among firms and their employees. Xiwei et al. (2010) use knowledge supply network to signal the need for attention to the flows of knowledge among actors in a supply chain network. They focus on the roles of each member in the KSN for providing knowledge. In particular, the role of universities and research centres as key sources of technological innovation are highlighted. This accords with network structure understood as the organizational form that assigns importance to each actor in fostering the learning process and innovation (Choi et al., 2004; Myers and Cheung, 2008; Wang et al., 2008; Lopez and Eldridge, 2010). Batenburg and Rutten's (2003) study of a regional supply chain network in a Dutch knowledge industry cluster provides useful insights for managing innovation. The importance of the unique contribution of a specific supplier and of creating trust in inter-organizational ties is acknowledged. Choi et al. (2004) study intellectual capital in the form of intellectual property management and its strategic importance for corporate success. They refer to a knowledge supply chain and models of licensing relationships. The importance of knowledge as the basis for a licensing relationship is highlighted. Lopez and Eldrige (2010) present a working prototype to promote the creation and control of the knowledge supply chain. They discuss the dissemination of best practice among supply chain practitioners. The terms used also demonstrate the intertwined nature of the two theoretical frameworks - knowledge and supply chain management. Knowledge flows and their management are hot topics in both literature streams (Hult et al., 2004, 2006; Modi and Mabert, 2007; Cheng et al., 2008; Blumenberg et al., 2009; Niemi et al., 2009; Pedroso and Nakano, 2009). Knowledge management is considered a tool for supply chain management and two main approaches exists. One proposes IT solutions as the main basis of every knowledge management activities, another considers the social aspect of knowledge transfer and, to improve it, proposes the improvements of CoPs (Hansen et al., 2005). The second approach focuses on the social architecture of knowledge exchange, highlights the importance of trust, cooperation and communication to foster knowledge transfer and learning among actors (Johanson and Vahlne, 2003; Khalfan et al., 2010; Kovacs and Spens, 2010). Within this second approach, we can find studies suggesting the need of considering different issues, especially human ones, for the effective implementation of knowledge management tools (Becker, 2001; Edwards et al., 2005).

The knowledge accumulation process within the supply chain, is closely related to the study of knowledge flows (Niemi et al., 2009, 2010). More research in this direction could provide new insights into improving supply chain performance. The fragmented nature of complex supply chains and the complex nature of knowledge highlighted in many papers (Ordonez de Pablos, 2002; Spekman et al., 2002; Desouza et al., 2003; Hall and Andriani, 2003), can lead to problems of knowledge obsolescence. This is another theme that requires further investigation. The role of knowledge within the supply chain for achieving superior firm performance requires more research.

The study in this thesis of knowledge flows in a supply chain context, differs from previous studies in three main directions:

1) SNA is used to map knowledge-based ties. The term knowledge-based ties has defined as implicit and explicit connections characterized by high levels of tacit knowledge and informal socialization mechanisms, and influenced by and embedded in human relationships (Lawson et al., 2009; Carey et al., 2011). Every organization can be considered a link in the chain of suppliers and consumers. All ties are connected through open collaboration to foster learning and develop new knowledge (Flynn et al., 1994; Hackman and Wageman, 1995). Learning is considered to be an activity triggered by a gap between potential and effective performance (Von hippel and Tyre, 1995), and generated by people's social interactions and the activities in which people engage (Nonaka, 1994);

2) SNA is complemented by OWA, applied to rank indirect ties and shed light on their performance as vehicles of knowledge transfer;

3) although the positive role of internal knowledge transfer, based mainly on direct ties among employees, has been widely recognized, the reinforcing relationship between internal and external knowledge transfer and their intertwined nature has been rather overlooked. In this study, the focus is on the process of knowledge creation and transfer,

and the role of effective management of knowledge-based ties for improving quality and, ultimately, increasing firms' operational performance. We show that the reinforcing relationship between external and internal knowledge transfer, and its intertwined nature, allow individuals to integrate their knowledge in the form of capabilities.

Two main research questions are investigated. First, how do organizations create new knowledge through their internal and external knowledge-based ties? Second, what is the impact of managing the knowledge-based relations on the operational performance? To address these questions, we use SNA to map the knowledge-based ties; OWA is applied to shed light on the role of indirect ties for transferring knowledge.

Supply chain networks have been studied mainly within the knowledge and supply chain management framework, given the useful insights they provide on the management of knowledge flows. Despite this interest in the network-based aspect of supply chains, real applications of the SNA to the supply chain context are scarce and focus on aspects such as flows of materials or information along a supply chain. This thesis takes a network-based approach, investigating two main aspects: the map of knowledge-based relationships among people, and the conditions leading to effective management of these relationships. SNA and OWA are applied to get a better understanding of the most knowledgeable individuals, who are expected to embody the most important knowledge and to be responsible for new knowledge creation. In particular, examination of indirect ties should allow a better understanding of the knowledge transfer process and, most important, provide insights into the role of indirect ties for transferring knowledge. This contributes to the literature on knowledge management in the supply context.

2.6. Conclusions

This thesis starts from the assumption that in a knowledge network, knowledge passes from one node to another, and indirect ties are vehicles of knowledge transfer. This applies to the case where nodes are patents, papers or people.

The two kinds of knowledge networks described in this chapter differ with respect to the time dimension. In a citation network, time is crucial, it leads to differences between forward and backward citations and influences the knowledge transfer and creation perspective. In the company supply chain network we do not discriminate time and we consider reciprocal ties.

Citation networks are a complex, but challenging study topic. So far, attention has been mainly on the most important or most connected nodes within a network, and the role of indirect ties among these nodes has been mostly ignored. It is important to know more about the most connected nodes: in a network, knowledge passes from one node to another, and the indirect ties account for complex knowledge flows. A method able to account for the indirect ties within a citations network would provide insights into the dynamics underlying knowledge creation. This thesis exploits OWA, already applied for preference ranking aggregation, in two applications.

1. In the first case, we assume a number of patents and their corresponding number of direct and indirect citations, with the aim of assessing a score for each patent. These scores reflect the impact of both direct and indirect citations on the longevity of the patents.
2. In the second case, we assume a number of people and their corresponding number of direct and indirect ties. In this case, the OWA operator is applied to

obtain a score to rank people, considering also their indirect ties. These scores reflect the impact of direct and indirect ties in the transfer of knowledge within networks.

Chapter 3 describes the main methods used to analyse networks of knowledge flows, and presents the main works applying these methods in the context of patent and supply chain networks.

Chapter 3. Methods for analysing networks of knowledge flows

3.1. Introduction

Interest in SNA has been growing and it has emerged as an interdisciplinary domain, which makes it very attractive to statisticians, mathematicians, sociologists and biologists. SNA has been used in the social sciences since the mid-1930s, with the first significant contribution in this field from researchers from the Manchester School (Barnes, 1954; Mitchell, 1969). Based on their reflections, the 'network' was discussed for the first time as an analytical concept to which graph theory could be applied.

An innovation in the use of SNA is its application to social relationships to look at the network of relationships among actors, in place of atomistic perspective. From an SNA perspective, the actor is no longer the point of interest, which is the main reason for proposing a social network approach to the study of knowledge flows. The SNA perspective emphasizes the importance of relationships and also includes informal connections. The informal network identified by SNA, is often the focus of learning (Cross and Parker, 2004). Within this area of research, scholars provided evidence that knowledge flows more easily through informal relationships than when following a formal organizational structure (Krackhardt and Hanson, 1993; Cross and Parker, 2004; Bryan and Joyce, 2005). The literature uses SNA applications to improve knowledge flows, to identify areas where connections are lacking, and to understand the nature and intensity of social ties (Kilduff and Tsai, 2003). The main assumption is that knowledge passes more easily through informal ties than formal ties. If knowledge is embedded in a network of relationships, that is, in the interactions among people, tools and tasks, then SNA can be used to find how the network is structured, which are the network's more embedded nodes, and how to access the knowledge accumulated and embedded in those relationships. The main output of this type of SNA application is the comparison between the formal organizational structures and the informal network of relations as emerged through the SNA. The aim of the comparison is to reveal that individuals who are less considered in the formal structure are, in contrast, central in the informal network of relationships. Figure 3.1 provides an example drawn from a study conducted by the IBM Institute for Business Value to compare formal and informal network structure of relationships (Cross et al., 2002).

Aston University

Illustration removed for copyright restrictions

Figure 3.1. Formal versus informal network in a company product division (source: Cross et al. 2002)

First, SNA is a tool for visualizing the map of knowledge flows. The main potential of SNA lies in its capacity to visualize relationships and to monitor information and knowledge flows (Cross and Parker, 2004), and in its ability to represent the relationship structure through a graph that enables quantitative and qualitative analysis. SNA maps different kinds of relationships among different actors. Chapter 2 referred to a widely used approach that focuses on mapping friendships, community and other kinds of personal networks where the source of data is social relations (Granovetter, 1973). Other applications of SNA point to knowledge relationships between co-authors (Katz and Martin, 1997; De Stefano et al., 2011), and patent and paper citation networks. This chapter examines the main methods used to map these relations.

The following sections provide a description of SNA methods, with illustrative examples, using the network depicted in Chapter 2 (Figure 2.3) which comprises 10 nodes, Nodes A, ….,J. Data are analysed using the Pajek[4] software, which is widely exploited for network analysis and can manage many nodes (up to 40 million).

3.2. Centrality measures

A first important step towards studying a network is analysis of node positions to assess their importance. Nodes are analysed in terms of their centrality, which provides information on how the centre and periphery relate. Centrality is a widely used measure in SNA to describe network characteristics. It identifies the position of the nodes within a network using various approaches (Freeman, 1979; Borgatti, 2005; Borgatti and Everett, 2006). One of the primary goals of a SNA application is identification of the 'important' nodes within a network. Wasserman and Faust (1994) state that importance is assimilated to prominence in the SNA perspective. In SNA, the central actors are likely to be the most influential actors and the most likely to be able to communicate options to others (Marsed and Friedkin, 1993). Centrality is a measure of power and influence and a greater number of connections is likely to endow importance. There are various definitions of centrality; here, we consider degree and closeness centrality.

<u>Degree centrality</u>

[4] Pajek is an open source software freely available athttp://pajek.imfm.si/doku.php?id=download

Degree centrality is a purely local measure, that is, a node with the most connections is the most important within the network and degree centrality can be defined as the number of ties incident upon a node (Freeman, 1979). Degree centrality was developed for undirected graphs; this thesis analyses directed networks, which show directionality, that is, each node can be both a 'sender' and a 'receiver'. Since they serve different functions, it is useful to distinguish between types of degree centrality:

- in-degree centrality refers to the number of in-coming ties;
- out-degree centrality refers to the number of out-going ties.

In directed networks, in-degree centrality is considered a measure of prestige, that is, of being chosen (number of incoming ties). For example, an actor has high *support*, if many people vote for him or her and, thus, is important in his or her network. It could be argued that in-degree centrality identifies the most important node, the most supported by others in the network.

An illustrative example

Consider the citations network depicted in Figure 2.3, in-degree centrality of Node A is 3, out-degree is 0.

Closeness centrality accounts for indirect ties among nodes. It indicates how easily a node can reach other nodes. A node is considered important if it is relatively close to all the others, and is defined as the inverse of the average distance between *i* and any other node:

$$C_c(i) = \frac{(n-1)}{\sum_{j \neq i} l(i,j)}$$

where

$l(i, j)$ = the number of ties in the shortest path between i to node j.

It can be argued that the closeness centrality measure provides information on how easily a node can reach other nodes.

Note that closeness centrality cannot be calculated for unconnected networks. A network is considered unconnected if there are no paths between each node pair. Citation networks are often unconnected since there can be weak and strong component[5] within complex citation networks and, in such cases, closeness centrality cannot be calculated.

An illustrative example

Consider the network depicted in Figure 2.3, n=10 and the sum of the distance connecting A to all the other nodes is 17 which is the sum of the following ties in the shortest path between A and all the others: A➔B (1), A➔B➔C (2), A➔D (1), A➔D➔F (2), A➔E (1), A➔D➔G (2), A➔D➔G➔I (3), A➔D➔H (2), A➔D➔H➔J (3). Closeness centrality of Node A is ${}^{9}/_{17} = 0.52$. Nodes G and H have the same number of ties (16) with all the others, so closeness centrality of G and H is ${}^{9}/_{16} = 0.56$.

3.3. SNA algorithms for citation networks

Within the SNA field, specific algorithms have been developed to map citation networks. The study of citations among documents has a long tradition. Since the work of Garfield (1964), the study of citations among scientific publications has received increased

[5] A graph can be disconnected in nature. 'The nodes in a disconnected graph may be partitioned into two or more subsets in which there are no paths between the nodes in different subsets. The connected subgraphs in a graph are called *components*. (…) A component is a subgraph in which there is a path between all pairs of nodes in the subgraph (all pairs of nodes in a component are reachable), and (since it is maximal) there is no path between a node in the component and any node not in the component. One cannot add another node to the subgraph and still retain the connectedness. If there is only one component in a graph, the graph is connected. If there is more than one component, the graph is disconnected.' (Wasserman and Faust, 1994, p. 110).

attention from network analysts, and the network analysis literature includes a growing number of contributions on identification of the so called 'main path', that is the main flows of ideas underlying the field of analysis (Whitley and Galliers, 2007; Nerur et al., 2008; Bhupatiraju et al., 2012; Colicchia and Strozzi, 2012), the technological development and the trajectory of scientific fields (Breschi et al., 2003; Mina et al., 2007; Verspagen, 2007; Fontana et al., 2009; Barberá-Tomás et al., 2011; Bekkers and Martinelli, 2012; Martinelli, 2012; Epicoco, 2013). These studies make use of the following algorithms.

- Search Path Link Count (SPLC) (Hummon and Doreian, 1989);
- Search Path Node Pair (SPNP) (Hummon and Doreian, 1989);
- Search Path Count (SPC) (Batagelj, 2003) and Critical Path Method (CPM);
- Hubs and authorities (Pinski and Narin, 1976; Kleinberg, 1999; Brandes and Willhalm, 2002; Batagelj, 2003);

3.4. Search Path Link Count (SPLC)

The Hummon and Doreain (1989) algorithms are very popular. Their innovation was to propose a different approach to citation analysis in which the connective threads through the network are preserved and the focus is on the ties rather than the nodes in the network. Hummon and Doreain's approach to the analysis of connectivity is to focus on sequences of ties and nodes, called *search paths*.

SPLC is a simple way of measuring the importance of a link, and implies specification of the following concepts. In a citation network the *startpoint* (initial unit) *s* is a vertex with zero in-degree, that is no arc is ending in that vertex, the *endpoint* (target unit) *t* is a vertex with zero outdegree, that is no arc is starting in that vertex. In Figure 2.3 vertices J, I, C are startpoints, while A is an endpoint. The *traversal weight* of an arc or a vertex is the proportion of all paths between the startpoint and the endpoint that contain this arc or vertex. SPLC consists of how many times one arc lies on all possible search paths between all startpoint nodes and endpoint nodes. It is based on counting the number of times a link is traversed by all possible search paths.

An illustrative example

In Figure 2.3, the citation arc DA obtains a SPLC value of 3. There are three possible search paths (J➔A; I➔A; C➔A). Arc 'DA' lies on these three.

3.5. Search Path Node Pair (SPNP)

SPNP is another algorithm elaborated by Hummon and Doreian (1989) and is based on the set of all search paths emanating from a startpoint node. It accounts for all connected node pairs along the search paths, and assigns to each arc the product of the number of its upstream and downstream vertices, thus, an arc in the middle will receive a higher value. The logic underlying SPNP is that citation arcs responsible for connecting higher numbers of nodes contain the most significant knowledge flows of the citation network.

An illustrative example

In Figure 2.3 the value of SPNP of arc 'DE' is the result of the product of 8 upstream vertices (D, B, C, H, F, G, I, J) to 2 downstream vertices (A, E), (8x2=16).

3.6. Search Path Count (SPC) and Critical Path Method (CPM)

Batagelji (2003) observes that the SPLC and SPNP description provided by Hummon and Doreain (1989) is rather imprecise and sought to improve it by introducing SPC for which the weight $N(u, v)$ for uRv counts the number of different paths from s to t through the arc (u, v). More specifically, Batagelji observes that SPLC is the SPC originating from each vertex (not only the *startpoints*). To compute $N(u, v)$, Batagelji introduces two auxiliary quantities: $N^{-}(v)$ denotes the number of different $s\text{–}v$ paths, and $N^{+}(v)$ denoted the number of different $v\text{–}t$ paths.

$$\boldsymbol{SPC = N(u, v) = N^{-}(u) \cdot N^{+}(v)}$$

Note that SPC is used to identify important small sub-networks on the basis of arc weights.

<u>*An illustrative example*</u>

In Figure 2.3 the arc GD obtains a SPC value of 1, since $N^{-}(G)=1$ (paths I➔G); and $N^{+}(D)=1$ (path D➔A). The small sub-network identified comprises Nodes A, E, D, H, G and I.

Batagelj (2003) also suggests applying the Critical Path Method (CPM) to the network. CPM comes from the operational research and can be used to detect the 'main path' in a citation network. CPM determines the $s\text{–}t$ path with the maximal value of the sum of weights arcs in the path and provides a visual display of broader longitudinal connectivity than the SPC output (Kejžar et al., 2010). In this thesis, an example of this application is provided in Chapter 4, which discusses the intellectual development of OWA research. Note that the aim of both algorithms is to reduce network complexity by highlighting only the most relevant nodes. The main difference between SPC and CPM is that the latter is broader than SPC and this is why we apply the CPM to presents the development of the OWA research. Looking at Figure 2.3, we have a small network to reduce and SPC results do not differ from CPM results. Both SPC and CPM highlight

Nodes A, E, D, H, G and I on the 'main path'. The network is a small one and may appear that SPC and CPM do not actually reduce the complexity of the network. In analysis of real datasets where citation networks are much larger and complex the identification of the 'main path' provides a significant reduction of the network.

3.7. Hubs and authorities

In the hubs and authorities algorithm, the authority is the core knowledge and the hubs are their best development. Hubs and authorities focus on the structure of the citation network and determine its prominent vertices. Hubs and authorities are formal notions of the structural prominence of vertices, identified according to their position on a graph.

Hubs and authorities rely on the assumption that, in directed networks, it is possible to identify these two important types of vertices: 'A vertex is a good authority, if it is pointed to by many good hubs, and it is a good hub, if it points to many good authorities' (Kleinberg, 1999, p. 8). For this reason it is considered a reinforcing relationship.

According to Brandes and Willhalm (2002) 'hubs and authorities are eigenvector centralities in the weighted undirected graphs constructed from a directed graph by means of bibliographic coupling and co-citation' (Brandes and Willhalm, 2002, p. 3). This algorithm was developed in the context of the worldwide web (WWW), which is a citations network with many pages (nodes) and ties among them. For this reason, the two vertices (hubs and authorities) of a page p can be defined as: $x(p)$ is an authority weight and $y(p)$ its hub weights.

The authority weight of page p is the sum of all hub weights of page q, for all q pointing to p. Then:

$$x(p) = \sum_{q:(q,p)} y(q)$$

The hub weight of page p is the sum of all authority weights of q for all q pointed to by p.

Then,

$$y(p) = \sum_{q:(p,q)} x(q)$$

The algorithm follows an iterative process. To begin with, each $x(p)$ and $y(p)$ is given an arbitrary nonzero value. Then the weights are updated in the following ways:

$$x_p^{(k)} = \sum_{q:(q,p)} y_q^{(k-1)}$$

and

$$y_p^{(k)} = \sum_{q:(p,q)} x_q^{(k)}$$

where k represents the current iteration and $k-1$ is the previous iteration. The weights are normalised so that $\sum_q (x_q^{(k)})^2 = 1$ and $\sum_q (y_q^{(k)})^2 = 1$.

In terms of matrices, the iterative process can be expressed as:

$x^{(k)} = A^T y^{(k-1)}$ and $y^{(k)} = Ax^{(k)}$, followed by the normalization in the 2-norm.

A is the adjacency matrix defined as

$$A_{(p,q)} \begin{cases} 1, & \text{if (p, q)is an arc in N} \\ 0, & \text{otherwise} \end{cases}$$

and A^T is the transposed matrix.

During each iteration hubs and authorities weights are updated until the numbers converge to a stationary solution.

Note that the two matrices used in this algorithm ($A^T A$) and AA^T are symmetric, while in a network the adjacency matrix is generally nonsymmetric, such as in the case of Figure 2.3.

An illustrative example

The adjacency matrix of the network depicted in Figure 2.3 is:

$$A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

And

$$A^T = \begin{bmatrix} 0 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

During the first iteration we assume $y^{(k-1)} = 1$.

The iterative algorithm has been run with software R[6], Table 3.1 and 3.2 show the results of 10 iterations, the numbers converge after the fourth iteration.

Node D obtains the highest authority weight, while Node A weight tends to decrease until a value of 0. Node C, I and J obtains a value of 0 from the first iteration, since no other node cites them. Similarly Node A is not an hub since no arc departs from it. The iteration sequence shows the dependence relationship between hubs and authorities: if a node points to many nodes with large x-values, it receives a large y-value, and if it is

[6] The R code for hubs and authorities algorithm is provided in the Appendix Chapter 3.

pointed to by many nodes with large y-values, it receives a large x-value. Intuitively, the network depicted in Figure 2.3 relies to some extent on Node A since all the others cite it either directly or indirectly. This aspect does not emerge from the hubs and authorities results. Based on these considerations, we can see that the hubs and authorities algorithm does not account for indirect ties.

Table 3.1. Convergence of the authority weights

Node	1st iteration	2nd iteration	3rd iteration	4th iteration	5th iteration	6th iteration	7th iteration	8th iteration	9th iteration	10th iteration
A	0.456	0.301	0.169	0.092	0.050	0.027	0.014	0.008	0.004	0.002
B	0.228	0.232	0.244	0.247	0.248	0.248	0.248	0.248	0.248	0.248
C	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
D	0.684	0.852	0.891	0.902	0.905	0.906	0.906	0.906	0.906	0.906
E	0.228	0.125	0.070	0.038	0.021	0.011	0.006	0.003	0.002	0.001
F	0.228	0.050	0.010	0.002	0.002	0.000	0.000	0.000	0.000	0.000
G	0.228	0.050	0.010	0.002	0.000	0.000	0.000	0.000	0.000	0.000
H	0.342	0.332	0.337	0.340	0.341	0.342	0.342	0.342	0.342	0.342
I	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
J	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3.2. Convergence of the hub weights

Node	1st iteration	2nd iteration	3rd iteration	4th iteration	5th iteration	6th iteration	7th iteration	8th iteration	9th iteration	10th iteration
A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
B	0.200	0.114	0.063	0.034	0.018	0.010	0.005	0.003	0.002	0.001
C	0.480	0.520	0.531	0.534	0.535	0.535	0.535	0.535	0.535	0.535
D	0.280	0.161	0.089	0.048	0.026	0.014	0.008	0.004	0.002	0.001
E	0.200	0.114	0.063	0.034	0.018	0.010	0.005	0.003	0.002	0.001
F	0.380	0.409	0.417	0.419	0.420	0.420	0.420	0.420	0.420	0.420
G	0.540	0.565	0.574	0.577	0.578	0.579	0.579	0.579	0.579	0.579
H	0.380	0.409	0.417	0.419	0.420	0.420	0.420	0.420	0.420	0.420
I	0.080	0.016	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000
J	0.160	0.157	0.158	0.158	0.158	0.158	0.159	0.159	0.159	0.159

3.8. Applications of the proposed methods in the literature

In this section, the main studies using the methods described above, are reviewed. For the purpose of this thesis, only studies dealing with the same kind of knowledge networks (citation and supply chain networks) as analysed in this work are discussed. These studies are summarized in Table 3.3.

Centrality measures have been applied to study knowledge networks and to understand some aspects of the knowledge transfer and creation process.

Hansen (2002) introduced the concept of knowledge network, referring to the different business units in a company and the access to the knowledge residing in each. To study the contacts of a business unit aimed at accessing the knowledge residing in another unit, the author considers in-degree, out-degree and closeness centrality measures of the company knowledge network and shows that some units are able to benefit from knowledge residing in other parts of the company while others are not and that project teams obtained more existing knowledge from other units and completed their projects faster to the extent that they had short interunit network paths to units that possessed related knowledge. He concludes that research on knowledge transfer should combine the concept of network connections and knowledge relatedness.

Allen et al. (2007) provide a case-study analysis to show the differences between the formal and informal knowledge networks in a research and development (R&D) context using SNA mapping. In this study, and the one described next, the authors do not make use of a specific SNA measure, but use the connections among members of the R&D units to map their informal relations, which is the primary purpose of SNA. Although these studies (this and the one described next) do not use the methods described in this thesis they are reported as important contributors to research on knowledge networks.

Capò-Vicedo et al. (2011) provide a social-network based model for improving knowledge management in multi-level supply chains formed of small and medium sized firms. They combine the map of the companies' network with data from semi-structured interviews and show that some factors, such as mutual trust and similar ways of thinking, are fundamental to encourage the knowledge creation process.

Kim et al. (2011) apply in-degree, out-degree and closeness centrality to three automotive supply networks to capture material flows among members. They show the usefulness of network concepts and measures to understand the structural characteristics of supply chain networks.

Borgatti and Li (2009) propose to apply the network concept to the supply chain and suggest the hubs and authorities algorithm to look at relationships among suppliers.

Since the early work of De Solla Price (1965) studies of citation networks use degree centrality to get a first snapshot of network complexity. Using first SPNP and SPLC, and then the SPC algorithm, they shift the emphasis from the importance of nodes to the importance of ties. Hummon and Doreian (1989) applied SPNP and SPLC for the first time to trace the path in research underlying DNA theory. They identified the important events or 'milestones' leading to the development of DNA theory. Other researchers have used the algorithms to analyse other scientific contexts or to improve the algorithms.

Pinski and Narin's (1976) work can be considered at the root of the hubs and authorities algorithm. They propose to measure the prominence of scientific journals by taking into account the prestige (in terms of citations received) of the journals that cite another journal.

Pieters et al. (1999) conduct a citation network analysis, based on the bibliometrics method, examining publications from the International Journal of Research in Marketing from 1981 to 1995 and identify groups of core marketing, methodology, managerial and psychology journals in the network.

Batagelj (2003) improves the SPNP and SPLC by proposing the SPC algorithm.

Batagelj et al. (2006) apply SPC to analyse the structure of a US patent network. They describe the main topics in the search activity carried out in the US between 1963 and 1999.

Cantner and Graf (2006) analyse the degree centrality measures of a patent citation network to describe the evolution of the innovator network in Jena, Germany, in the period 1995 to 2001. The analysis identifies inventors that are patent applicants, thus, the knowledge network studied is a network of interpersonal relations. The aim was to observe the evolution of collaboration among inventors.

Mina et al. (2007) apply SPC and CPM to identify the evolutionary trajectories in medical knowledge. They use a bibliographic database of 11,240 papers published in the area of coronary artery disease, between 1979 and 2003, and a patent dataset of 5,136 US patents documents granted between 1976 and 2003 for angioplasty-related devices. They found that SPC and CPM deployed on the paper and patent citation networks produced results that correspond very closely to the qualitative evidence available in numerous medical surveys.

Verspagen (2007) maps the technological trajectory of fuel cell research by analysing patent citation networks using Hummon and Doreain's (1989) algorithms. He proposes an extension to these algorithms to find the top main path, which is the path showing the highest sum of SPLC and SPNP.

Calero-Medina and Noyons (2008) apply SPC and hubs and authorities algorithms to the case of 'absorptive capacity'. They build a citations network for papers citing the pioneering work of Cohen and Levinthal (1990) between 1990 and 2005, to trace the intellectual trajectory of the field of interest, and apply hubs and authorities to identify the core contributions.

Fontana et al. (2009) map the technological trajectory of Local Area Networks (LANs) by analysing the corresponding patent citations network. They identify the most significant inventions related to the Ethernet using the SPLC and SPNP algorithms.

Barbera-Tomas et al. (2011) study the technological evolution of a surgical prosthesis, the artificial spinal disc, using the SPLC and SPNP to analyse patent citation networks. They combine these methods with qualitative interviews with experts in the field and find support for their results identifying the most relevant inventions in the field.

Bhupatiraju et al. (2012) study knowledge flows in the core innovation, entrepreneurship and science and technology literatures. They use SPLC and SPNP to perform main path analysis of the three lists of core contributions, and compare the outcomes of this network analysis with the picture that emerges from the three separate field studies. For each field of study the main trajectory is identified and described.

Martinelli (2012) investigates the evolution of the telecommunications switching industry using the SPLC and SPNP algorithms. She analyses patent citation networks to conduct an in-depth analysis of the technological direction, technical bottlenecks, and engineering heuristics over seven generations of technological inventions in the industry.

Colicchia and Strozzi (2012) conduct a literature survey using paper citation network analysis to investigate the supply chain risk management literature. They deploy the SPLC, SPNP and SPC algorithms to trace the main path of research in the field and to identify the most relevant contributions.

Epicoco (2013) applies the SPNP, SPLC and hubs and authorities algorithms to map the trajectory of semiconductor miniaturization using patent citations between 1976 and 2008. She identifies three dimensions of patterns of technological change and characterizes them in terms of distinctive knowledge properties.

Liu et al. (2013) conduct a literature survey on the development of Data Envelopment Analysis (DEA) using papers published between 1978 and 2010. They employ the SPC algorithm and integrate it with an importance index for each link in the citation network.

Emrouznejad and Marra (2014) trace the intellectual trajectory of OWA, applying the CPM, which is a slightly different version of Chapter 4 in this thesis.

Table 3.3. Relevant literature using SNA methods to investigate knowledge flows in knowledge networks (in chronological order)

Authors and year	Method	Aim
Garfield et al. (1964)	Bibliographic citation using the 1961 Science Citation Index	Construction of a topological network diagram for 40 milestone events as described by Asimov.
De Solla Price (1965)	In-degree centrality	Describing structure and dynamics of citation networks
Pinski and Narin (1976)	Three measures: a) a size independent influence weight for each journal or aggregate; b)	Describe the structure of US patent citations network to the study of innovations and

	influence per publication; c) total influence	technical changes.
Hummon and Doreian (1989)	SPLC and SPNP	Identifying the main path of research that lead to the development of the DNA theory.
Pieters et al. (1999)	Citation analysis; Social networks; Bibliometrics	Examine simultaneously the importance and similarity of journals in the network over time.
Hansen (2002)	In-degree; out-degree; closeness centrality	Examine the role of ties to get access to knowledge residing in different company's units.
Batagelj (2003)	SPC	Advance the SPLC algorithm
Batagelj et al. (2006)	SPC	Map the structure of US patent citation network.
Allen et al. (2007)	SNA to map informal relations	Discuss the role of informal networks in the development, exchange and dissemination of knowledge within the company's R&D unit.
Cantner and Graf (2006)	Combination the use of degree centrality measure and OLS – multiple regression analysis with dyadic data	Mapping the network of collaboration between innovators.
Mina et al. (2007)	SPLC and SPNP	Mapping the evolutionary trajectory of innovation if medical knowledge.
Verspagen (2007)	SPLC and SPNP	Mapping the technological trajectory in patent citation network of fuel research.
Calero Medina and Noyons (2008)	SPC and hubs and authorities	Identifying the main path in the field of 'absorptive capacity' theory.
Borgatti and Li (2009)	Hubs and authorities	Proposing the SNA concepts and hubs and authorities in particular to analyse relations among suppliers.
Fontana et al. (2009)	SPLC and SPNP	Mapping the technological trajectory of Local Area Networks (LANs) by analysing the corresponding patent citation network.
Barberá-Tomás et al. (2011)	SPNP and SPLC	Conducting a connectivity analysis of citation networks in the field of surgical prosthesis.
Capò-Vicedo et al. (2011)	Centrality measures	Providing a social network-based model for improving knowledge management in multi-level

		supply chains formed by small and medium-sized enterprises
Bhupatiraju et al. (2012)	SPNP and SPLC	Analysing the literature of innovation, entrepreneurship and science and technology systems
Martinelli (2012)	SPNP and SPLC	Tracing the technological trajectory of the telecommunication switching industry.
Kim et al. (2011)	SNA to map materials flows and contractual relationships	Analysing the supply networks in terms of both materials flow and contractual relationships.
Colicchia and Strozzi (2012)	SPLC, SPNP, SPC	Literature review on supply chain risk management.
Epicoco (2013)	CPM and hubs and authorities	Mapping the semiconductor miniaturization trajectory.
Liu et al. (2013)	SPC	Literature review on Data Envelopment Analysis (DEA).
Emrouznejad and Marra (2014)	CPM	Literature review on Ordered Weighted Averaging (OWA) operators.

3.9. Conclusions

This chapter has presented the main methods used to analyse networks of knowledge flows and their application in the literature dealing with citation and supply chain networks. Supply chain networks studies mainly use SNA to map different type of relations among individuals or companies, making use of centrality measures and one of the SNA main outputs that is the map of informal relations. Citation networks, either patents or papers, are analysed by means of SPLC, SPNP, SPC and CPM to trace the main flows of ideas or using hubs and authorities to detect the most prominent vertices which are considered to be the core contributions in terms of knowledge within the network. In the studies presented, indirect ties/citations are overlooked and the methods proposed do not capture their role in a network as vehicle of knowledge transfer.

It can be concluded that the hubs and authorities algorithm focuses on the structure of the network and highlights prominent vertices. Given the reinforcing relationship between hubs and authorities, in this thesis authorities are the core knowledge nodes in the network under investigation, and hubs are their best developments. To account for the underlying nodes in networks, such as Node A in Figure 2.3, this thesis compares the SNA results with the OWA analysis to show that the OWA applied is able to account for the network evolution of a node, assessing a value that considers the number of direct and indirect ties received by a node.

Chapter 4. Ordered Weighted Averaging Operators

4.1 Introduction

Chapter 3 described the most frequent methods used to analyse networks of knowledge flows and highlighted the drawbacks of not considering indirect ties. This thesis uses OWA to analyse indirect ties in networks and obtain ranking among nodes (patents or individuals) and identify the crucial role of indirect as well as direct ties. To introduce the OWA model and explain its popularity in several disciplines, this chapter presents the development of OWA from its first conceptualization (Yager, 1988) to its most recent developments. The aim is to show how OWA has been applied in several contexts and can be used to study networks such as the two in this thesis. A detailed illustration of current approaches is presented to introduce the model selected for this thesis. It belongs to an established tradition dealing with the minimax disparity approach proposed by Wang and Parkan (2005), using Linear Programming (LP). The relevant research is described in this chapter and the proposed model presented.

The family of OWA operators was first introduced by Yager (1988) as a tool to deal with the problem of aggregating multicriteria to form an overall decision function. Yager described them as cumulative operators for membership aggregation. Following this conceptualization, the OWA weighting vector has been highlighted as a means to introduce the decision maker's attitude (Yager, 1995a), and the OWA operator has received great attention and been applied in different disciplinary contexts, for example, decision making under uncertainty (Yager and Kreinovich, 1999), fuzzy system and Information Retrieval System (IRS) (Kacprzyk and Zadrożny, 2001; Herrera-Viedma et al., 2003), and data mining (Torra, 2004). OWA operators have been used in several different research fields, but the present study is the first work to depict the OWA development scenario and describe its development path. This chapter reviews the growing literature on the OWA operator and traces the development of OWA research using CPM. CPM was chosen over the SPC described in Chapter 3 since it allows the 'main path' of ideas in a discipline to be traced, and provides more detail. Based on an initial sample of 537 papers (see Section 4.3), CPM is able to reflect the direction of research in this area in a more complete manner than allowed by SPC. We describe the intellectual structure of this field of research and its main sub-areas. The selected OWA model used for this analysis of indirect ties in knowledge networks is also described.

4.2 The OWA operators: Background

The formulation of OWA, as originally proposed by Yager (1988), refers to the issue of aggregating criteria functions to form an overall decision function.

Definition: A mapping F from

$$I^n \rightarrow I \text{ (where } I = [0,1])$$

is called an OWA operator of dimension n if associate with F, is a weighting vector W,

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}$$

such that

$$W_i \in [0,1]$$

$$\sum_{i=1}^{n} w_i = 1$$

$$\mathbf{F(a_1, a_2, \ldots, a_n) = W_1 b_1 + W_2 b_2 + \cdots + W_n b_n,}$$

where b_1 is the largest element in the collection $a_1, a_2, \dots, a_n.$ An n vector B can be the ordered argument vector if each element $b_i \in [0,1]$ and $b_i \geq b_j$ if $j > i$. Given and OWA operator F with weight vector W and an argument tuple $(a_1, a_2, \dots, a_n.)$ we can associate with this tuple an ordered input vector B which is the vector consisting of the argument of F put in descending order. Using this notation then

$$\mathbf{F}\ (a_1, a_2, \dots, a_n.) = \mathbf{W}'\mathbf{B},$$

the inner product of W′ and B. It is also possible to denote $\mathbf{F}\ (a_1, a_2, \dots, a_n.)$ as F(B) where B is the highest associated ordered argument vector.

Yager (1988) also points out that the weights, the W′s, are associated with a particular ordered position rather than a particular element, that is, W_i is the weight associated with the i-th largest vector B.

4.3 Data

Papers were selected from ISI Web of Science (WoS), which is the source of data for this study. OWA papers were searched and retrieved using the keywords 'ordered weighted averaging'. Of the first 540 results, 3 were not imported since they did not belong to the Core Collection within ISI WoS, thus, the procedure produced 537 results, 674 authors and 249 journals. A major issue when searching for OWA papers is the correct 'search key'; we used the keywords 'ordered weighted averaging' rather than the abbreviation OWA to avoid potential misunderstanding.

4.4 OWA knowledge accumulation using the Critical Path Method

Figure 4.1 shows the results of the CPM, which captures the evolution and direction of knowledge accumulation. The graph shows the sequence of knowledge contributions. The figure should be read from the bottom (older contributions) to the top (most recent contributions). The first four papers by Yager constitute the knowledge base of the main path of ideas in this research area. The path goes in two directions from the base, to the left and to the right. The right hand path is enclosed in a red dotted line to highlight the stream of research on which the OWA model applied in this thesis relies.

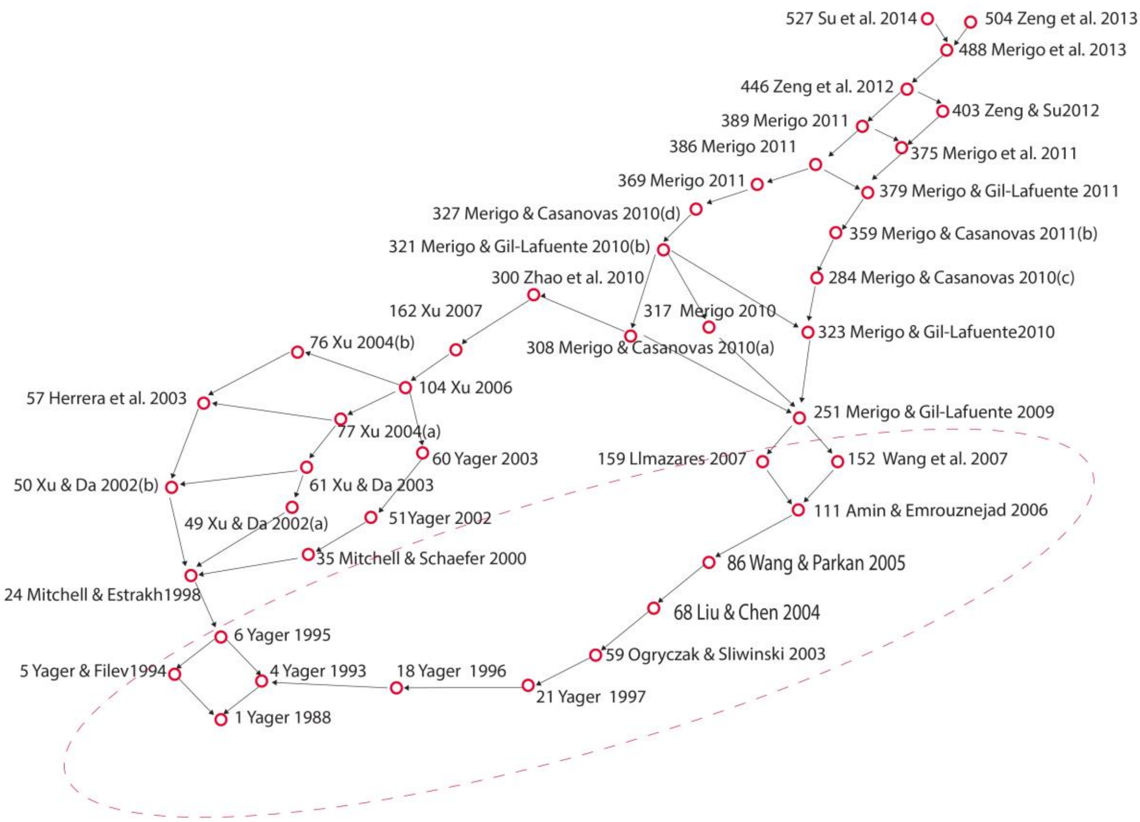

Figure 4.1. Critical Path Method of OWA development

After examining the title, abstract and keywords[7] of these papers (Table 4.2) the development of this discipline and its major areas of research are described. The content analysis reveals the efforts of researchers focused on two major directions.

The first works by Yager (1988, 1993, 1995b) and Yager and Filev (1994) constitute the knowledge base for future work and developments and applications of the OWA method. They lay the foundation for this research topic. Yager (1988) deals with the problem of

[7] Some journals such as *International Journal of Intelligent Systems* and *IEEE Transactions on Systems, Man and Cybernetics*, do not provide keywords. In these cases, the keywords reported in Table 4.2 are based on words that recur in the paper, and are in italic font.

aggregating multiple criteria to form an overall decision function and introduces the notion of 'orness', which refers to the 'and-like' or 'or-like' aggregation result of an OWA operator. Thus the operator lies between two extremes, 1 ('and-like') and 0 ('or-like'), the former relates to the situation in which all criteria are satisfied. The latter refers to the situation where at least one of the criteria has to be satisfied. The 11 values between 0 and 1 depend on the decision maker's expertise and are supposed to reflect his or her degree of optimism. The 'orness' concept has received great attention and further specification (Marichal, 1999; Fernández Salido and Murakami, 2003; Ronald R. Yager, 2004).

On the left hand side of the graph, we can identify a branch of literature that includes a group of works that generalize the OWA operator to include the case of real-number and fuzzy ranks (Mitchell and Estrakh, 1998); use a multiple priority induced OWA operator (Mitchell and Schaefer, 2000); propose new classes of aggregation operators such as the ordered weighted geometric averaging (OWGA) operators (Xu and Da, 2002a); investigate the uncertain OWA operator in which the associated weighting parameters cannot be specified, but value ranges can be obtained and each input argument given in the form of an interval of numerical values (Xu and Da, 2002b); and investigate the ordered weighted geometric (OWG) operator and its relationship to the OWA operator in multi-criteria decision making (MCDM) (Herrera et al., 2003). Within this area we find two more papers by Yager. One deals with fuzzy methods to model nearest neighbour rules (Yager, 2002) and the other discusses induced OWA operators (IOWA) (Yager, 2003) that receive further attention in this sub area identified. Xu and Da (2003) propose the induced ordered weighted geometric averaging (IOWGA) operator, as a new aggregator, and the generalized induced linguistic aggregation operators (Xu, 2006). Two papers by Xu (Xu, 2004a, 2004b) extend the OWA, proposing the (EOWA) operator and the uncertain linguistic ordered weighted averaging (ULOWA) operator and the uncertain linguistic hybrid aggregation (ULHA) operator.

Later research focuses on fuzzy aggregation and fuzzy-set theory. In this strand of work the CPM highlights the following as the most significant contributions. Xu (2007) propose an intuitionistic fuzzy version of the OWA operator (IFOWA); Zhao et al. (2010) extend the generalized OWA operators introduced by Yager (2004) to the intuitionistic fuzzy information. Merigó and Casanovas (2010a) present a series of operators, the fuzzy generalized hybrid averaging (FGHA) operator, the fuzzy induced generalized hybrid averaging (FIGHA) operator, the Quasi-FHA operator and the Quasi-FIHA operator, with the advantage of generalize a wide range of fuzzy aggregation operators that can be used in different contexts such as decision making problems.

On the right side of the figure is Yager's (1996) paper on the problem of maximizing an OWA aggregation of a group of variables that are interrelated and constrained by a collection of linear inequality. In this paper, Yager models the problem as a LP problem. He later proposes the OWA operator as an analytic formulation for the Leximin method, to overcome its lack of analytic formulation (Yager, 1997). Following these conceptualizations, researchers worked on the linear programming formulations with the OWA objective functions (Ogryczak and Śliwiński, 2003; Liu and Chen, 2004; Wang and Parkan, 2005; Amin and Emrouznejad, 2006). However, there are differences in the various approaches using linear programming. According to Ogryczak and Śliwiński (2003), the LP problem with the OWA objective can be performed as a standard linear problem and two alternative LP formulations are introduced - the max-min and the deviation model. Liu and Chen (2004) propose the concept of parametric geometric OWA operator (PGOWA) and parametric maximum entropy OWA operator (PMEOWA) showing the consistence of the orness level and the aggregation value for an aggregated element with PGOWA. The equivalence between PGOWA and PMEOWA is also proven.

Wang and Parkan's (2005) paper represents the first attempt to propose the minimax disparity approach as a method to identify OWA operator weights using LP under a given level of 'orness'. It is presented below; the model applied in this thesis builds on this research. According to this approach, OWA operator weights are determined by minimizing the maximum difference between two adjacent weights, under a given level of 'orness'.

$$\min \delta$$

$$s.t. \frac{1}{n-1}\sum_{i=1}^{n}(n-i)w_i = \alpha$$

$$-\delta \leq \mathbf{w_i} - \mathbf{w_{i+1}} \leq \boldsymbol{\delta}, \qquad \mathbf{i = 1, \ldots, n-1,}$$

$$\sum_{i=1}^{n} w_i = 1,$$

$$\mathbf{w_i \geq 0, i = 1, \ldots, n.}$$

Amin and Emrouznejad (2006) extend the minimax disparity to determine the OWA model based on LP and introduce the minimax disparity approach between any distinct pairs of the weights

$$\min \delta$$

$$\mathbf{s.t.}\ \frac{\mathbf{1}}{\mathbf{n-1}}\sum_{\mathbf{i=1}}^{\mathbf{n}}(\mathbf{n-i})\mathbf{w_i} = \boldsymbol{\alpha} = \mathbf{Orness\ (w),} \leq \boldsymbol{\alpha} \leq \mathbf{1,}$$

$$-\delta \leq \mathbf{w_i} - \mathbf{w_j} \leq \boldsymbol{\delta}, \mathbf{i = 1, \ldots, n-1,} \qquad \mathbf{j = i+1, \ldots, n,}$$

$$\sum_{i=1}^{n} w_i = 1,$$

$$\mathbf{w_i \geq 0, i = 1, \dots, n.}$$

This model differs from Wang and Parkan (2005) model by minimizing the maximum disparity of any distinct pairs of weights instead of adjacent weights. Minimizing the maximum difference between two adjacent weights is a very strong constraint in the disparity approach that renders the weights less usable in practice.

A new disparity model that imposes fewer restrictions on the disparity between w_j and w_i, and better discriminate among places, was proposed by Emrouznejad and Amin (2010). This model, which can be used to aggregate the preference ranking system, is applied in the present thesis and defined as follows:

$$\min \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \delta_{ij}$$

$$\mathbf{s.t.} \frac{1}{n-1} \sum_{i=1}^{n} (n-i)\, w_i = \alpha = \mathrm{Orness}(w), 0 \leq \alpha \leq 1$$

$$-\delta_{ij} \leq w_i - w_j \leq \delta_{ij}, \qquad i = 1, \dots, n-1 \quad j = i+1 \dots, n,$$

$$\sum_{i=1}^{n} w_i = 1,$$

$$\mathbf{w_i \geq 0, i = 1, \dots, n,}$$

$$\delta_{ij} \geq 0, i = 1, \dots, n-1, j = i+1, \dots, n.$$

An illustrative example

Assume there are 8 patents, i = 1,…,8. Let us use j (j = 1,…,5) represents the places, i.e. j=1 means number of direct citations, j=2, means number of indirect citations in the second place, and so on. The numbers of direct and indirect citations for the selected 8 patents are listed in Table 4.1. As seen in this table, there are five different places; hence, we determine an OWA vector of five elements, i.e. $n = 5$, using the formulation proposed by Emrouznejad and Amin (2010).

Table 4.1. Number of patent citations related to selected 8 patents

Patents	1st Place	2nd Place	3rd Place	4th Place	5th Place
P1	4	0	0	0	0
P2	10	62	21	4	1
P3	9	6	1	1	0
P4	8	27	38	30	13
P5	2	6	1	0	0
P6	9	24	35	20	19
P7	3	6	14	56	45
P8	4	3	0	0	0

To find an OWA weight vector for aggregation of the above patents analysis the Emrouznejad and Amin (2010) model can be expressed in the following form.

$$
\begin{aligned}
&\min\ \delta_{12}+\delta_{13}+\delta_{14}+\delta_{15}+\delta_{23}+\delta_{24}+\delta_{25}+\delta_{34}+\delta_{35}+\delta_{45}\\
&s.t.\\
&\quad Orness(\mathbf{w}) = w_1+\frac{3}{4}w_2+\frac{2}{4}w_3+\frac{1}{4}w_4=\alpha \qquad \alpha\in(0.5,1)\\
&\quad -\delta_{ij}\le w_i-w_j\le\delta_{ij} \qquad i=1,2,3,4\ j=i+1,\ldots,5\\
&\quad w_1+w_2+w_3+w_4+w_5=1\\
&\quad w_i\ge 0\ \ i=1,\ldots,5\\
&\quad \delta_{ij}\ge 0\ \ i=1,2,3,4,\ j=i+1,\ldots,5
\end{aligned}
$$

In line with the properties of this OWA disparity model we need to choose an orness level $\alpha\in(0.5,1)$ for which $w_1^*>w_2^*>w_3^*>w_4^*>w_5^*>0$.

Assume $\alpha = 0.70$

Then we have

	w_1^*	w_2^*	w_3^*	w_4^*	w_5^*

$\alpha = 0.70$	0.4	0.24	0.18	0.12	0.06

And the results

Patents	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
OWA score	1.6	32.18	5.34	29.3	3.06	26.18	36.62	2.32

That means: $P_7 > P_2 > P_4 > P_6 > P_3 > P_5 > P_8 > P_1$.

This model is used in this thesis to determine the OWA weights associated with direct and indirect ties. It has been shown that this model is more general than the disparity OWA weights determination model and generates valid OWAs (Emrouznejad and Amin, 2010). Furthermore it accounts for differences among places in a better way than Amin and Emrouznejad (2006) previous model. It complements existing disparity models, such as the ones developed by Wang and Parkan (2005) and Amin and Emrouznejad (2006), rather than superseding them. The authors show that it can be used for a preference ranking aggregation. Thus, it is in line with the stream of research highlighted by the CPM results, although it does not appear as one of the papers along the trajectory.

A further justification for using the OWA to rank patent citations is that the decision maker, which in the analysis of patent citation networks might be policy makers or network analysts, wants his or her decision to take account of the role of time as well as indirect citations. While in the case of relation knowledge-based ties among individuals, the OWA weights allow a ranking of knowledge-based relations, taking a different perspective on the role of those individuals not the most central, is equally important in the knowledge transfer and knowledge creation process.

Drawing on this work, the sub area identified between 2007 and 2009 (Llamazares, 2007; Wang et al., 2007; Merigó and Gil-Lafuente, 2009) advances this research, developing models that are slightly different from the previous ones. More specifically, Wang et al.'s (2007) paper deals with the determination of weights for different rank places. Their model allows the weights associated with different rankings to be determined according to the decision maker's level of optimism, which is characterized by an orness degree. Llamazares (2007) determines the OWA operator weights that allow to extend, through the OWA operator, some classes of majority rules that emerge if individuals do not grade their preferences between two alternatives. Merigó and Gil-Lafuente's (2009), study can be seen as bridging between the previous two lines of research. This new area relies on both lines of previous research and comprises work that focuses mainly on induced and fuzzy OWA operators. Merigó and Gil-Lafuente (2009) and Merigó and Casanovas (2010b) build on the previous line of research and propose the induced generalized ordered weighted averaging (IGOWA) operator. This is a new aggregation operator that generalizes the OWA operator, and includes the main characteristics of both the generalized OWA and the induced OWA operator. They propose application of the IGOWA in a financial decision making problem. Merigó (2010) develops a decision making model with probabilistic information and uses the concept of the immediate probability to aggregate the information and apply it to the selection of strategies. Merigó and Gil-Lafuente (2010) apply the ordered weighted averaging distance (OWAD) operator and the ordered weighted averaging adequacy coefficient (OWAAC) operator to the selection of financial products. This line of research was extended by Merigó and co-authors who successfully apply the proposed models to other disciplinary contexts such as strategic and business decision making (Merigó and Casanovas, 2010c, 2011a). They also developed a decision making model with distance measures, using linguistic aggregation operators. They propose a linguistic ordered weighted averaging distance (LOWAD) operator and apply it to support decision makers in human resource management (Merigó and Casanovas, 2010d). They developed a subsequent OWA model using distance measures and induced aggregation operators (Merigó and Casanovas, 2011b). This model provides a parameterized family of distance aggregation operators between the maximum and the minimum distance, based on a complex reordering process that reflects the complex attitudinal character of the decision-maker. The fuzzy induced generalized aggregation operators (FIGOWA) have been proposed also for strategic multi-person decision making (Merigó and Gil-Lafuente, 2011). Merigó also developed a model that uses the weighted average (WA) and induced ordered weighted averaging (IOWA) operator in the same formulation, and applies it to multi-person decision making in political management (Merigó, 2011).

Table 4.2. Papers on the CPM

Id	Authors	Title	Journal	Keywords	Year published
1	Yager, R.R.	On ordered weighted averaging operators in multicriteria decision making	IEEE Transactions on Systems Man and Cybernetics	Ordered weighted averaging operators, decision making	1988
4	Yager, R. R.	Families of OWA operators	Fuzzy Sets and Systems	Aggregation; fuzzy sets; averaging operators; linguistic quantifiers; logical operators	1993
5	Yager, R. R.; Filev, D R.	Parameterized and-like and or-like OWA operators	International Journal of General Systems	Aggregation operators; decision making; averaging operators; fuzzy	1994

				set theory; fuzzy logic control	
6	Yager, R.R.	Measures of entropy and fuzziness related to aggregation operators	Information Sciences	Entropy measures	1995
18	Yager, R. R.	Constrained OWA aggregation	Fuzzy Sets and Systems	*Fuzzy mathematical programming*; linguistic quantifiers; constrained optimization; OWA operators	1996
21	Yager, R. R.	On the analytic representation of the Leximin ordering and its application to flexible constraint propagation	European Journal of Operational Research	Aggregation; constraint propagation; fuzzy sets; OWA operators; Leximin; mathematical programming	1997
24	Mitchell, H B.; Estrakh, D. D.	An OWA operator with fuzzy ranks	International Journal of Intelligent Systems	*Fuzzy ranks*	1998
35	Mitchell, H B.; Schaefer, P. A.	Multiple priorities in an induced ordered weighted averaging operator	International Journal of Intelligent Systems	*Multiple fuzzy priorities*	2000
49	Xu,, Z.S.; Da, Q. L.	The uncertain OWA operator	International Journal of Intelligent Systems	*Internal numbers; uncertain OWA operator*	2002
50	Xu,, Z.S.; Da, Q. L.	The ordered weighted geometric averaging operators	International Journal of Intelligent Systems	*Ordered weighted geometric averaging operators*	2002
51	Yager, R. R.	Using fuzzy methods to model nearest neighbour rules	IEEE Transactions on Systems Man and Cybernetics part B-Cybernetics	Nearest-neighbour models	2002
57	Herrera, F., Herrera-	A study of the origin and uses of	International Journal of	*Ordered weighted geometric*	2003

	Viedma, E., Chiclana, F.	the ordered weighted Geometric operator in multicriteria decision making	Intelligent Systems	*operator; multicriteria decision making*	
59	Ogryczak, W.; Sliwinski, T.	On solving linear programmes with the ordered weighted averaging objective	European Journal of Operational Research	Equity; lexicographic maximin; *linear programming*; multiple criteria; ordered weighted averaging	2003
60	Yager, R. R.	Induced aggregation operators	Fuzzy Sets and Systems	IOWA operator; OWA aggregation operators; best yesterday models	2003
61	Xu, Z. S.; Da, Q. L.	An overview of operators for aggregating information	International Journal of Intelligent Systems	*Survey; aggregation operators*	2003
68	Liu, X. W.; Chen, L. H.	On the properties of parametric geometric OWA operator	International Journal of Approximate Reasoning	OWA operator; geometric OWA operator; maximum entropy OWA operator	2004
76	Xu, Z. S.	EOWA and EOWG operators for aggregating linguistic labels based on linguistic preference relations	International Journal of Uncertainty Fuzziness and Knowledge-based Systems	Group decision making; multiplicative linguistic preference relations; additive linguistic preference relations; extended ordered weighted averaging (EOWA) operator	2004
77	Xu, Z. S.	Uncertain linguistic aggregation	Information Sciences	Aggregation; multiple	2004

		operators based approach to multiple attribute group decision making under uncertain linguistic environment		attribute group decision making; uncertain linguistic ordered weighted averaging (ULOWA) operator; uncertain linguistic hybrid aggregation (ULHA) operator	
86	Wang, Y. M.; Parkan, C.	A minimax disparity approach for obtaining OWA operator weights	Information Sciences	OWA operator; Operator weights; Degree of orness; Minimax	2005
104	Xu, Z. S.	On generalized induced linguistic aggregation operators	International Journal of General Systems	Generalized induced linguistic aggregation operators, linguistic variable, uncertain linguistic variable, operational laws	2006
111	Amin, G. R., Emrouznejad, A.	An extended minimax disparity to determine the OWA operator weights	Computers & Industrial Engineering	OWA operator weights; *duality of linear programming*	2006
152	Wang, Y. M.; Luo, Y.; Hua, Z.	Aggregating preference rankings using OWA operator weights	Information Sciences	Preference ranking; preference aggregation; OWA operator weights; orness degree	2007
159	Llamazares, B.	Choosing OWA operator weights in the field of Social Choice	Information Sciences	Ordered weighted averaging operators; aggregation	2007

				operator weights; majority rules	
162	Xu, S. Z.	Intuitionistic fuzzy aggregation operators	IEEE Transactions on Fuzzy Systems	Intuitionistic fuzzy hybrid aggregation, intuitionistic fuzzy ordered weighted averaging (IFOWA)	2007
250	Merigó, J. M.; Gil-Lafuente, A. M.	The induced generalized OWA operator	Information Sciences	Aggregation operators; OWA operators; generalized mean; quasi-arithmetic mean; decision making	2009
284	Merigó, J. M.; Casanovas, M.	The fuzzy generalized OWA operator and its application in strategic decision making	Cybernetics and Systems	Aggregation operators; decision making; fuzzy OWA operator; selection of strategies	2010
300	Zhao, H.; Xu, Z.; Ni, M.; Liu, S.	Generalized aggregation operators for intuitionistic fuzzy sets	International Journal of Intelligent Systems	*Generalized intuitionistic fuzzy weighted averaging operator*	2010
308	Merigó, J. M.; Casanovas, M.	Fuzzy generalized hybrid aggregation operators and its application in fuzzy decision making	International Journal of Fuzzy Systems	Aggregation operators; fuzzy numbers; hybrid averaging; OWA operator; decision making	2010
316	Merigó, J. M.	Fuzzy decision making with immediate probabilities	Computers & Industrial Engineering	Decision-making; immediate probabilities; OWA operator; fuzzy numbers; strategic selection	2010
321	Merigó, J. M.; Casanovas, M.	Induced and heavy aggregation operators with	Journal of Systems Engineering and	It is called the induced heavy ordered	2010

		distance measures	Electronics	weighted averaging (OWA) distance (IHOWAD) operator.	
323	Merigó, J. M.; Gil-Lafuente, A. M.	New decision making techniques and their application in the selection of financial products	Information Sciences	Decision making; OWA operator; selection of financial products; hamming distance	2010
327	Merigó, J. M.; Casanovas, M.	Decision making with distance measures and linguistic aggregation operators	International Journal of Fuzzy Systems	Linguistic ordered weighted averaging distance (LOWAD) operator	2010
359	Merigó, J. M.; Casanovas, M.	Decision-making with distance measures and induced aggregation operators	Computers & Industrial Engineering	Decision-making; OWA operator; distance measures; induced aggregation operators	2011
369	Merigó, J. M.; Casanovas, M.	Induced aggregation operators in the Euclidean distance and its application in financial decision making	Expert Systems with Applications	Induced aggregation operators; Euclidean distance; decision making; selection of investment	2011
375	Merigó, J. M.; Gil-Lafuente, A. M.; Gil-Aluja, J.	Soft computing techniques for decision making with induced aggregation operators	Information-An International International Journal	*Induced aggregation operators; induced ordered weighted averaging; induced ordered weighted averaging adequacy coefficient operator*	2011
379	Merigó, J. M.;	Fuzzy induced	Expert Systems	Aggregation	2011

	Gil-Lafuente, A. M.	generalized aggregation operators and its application in multi-person decision making	with Applications	operator; OWA operator; fuzzy numbers; multi-person decision making	
386	Merigó, J. M.	A unified model between the weighted average and the induced OWA operator	Expert Systems with Applications	Weighted average; OWA operator; aggregation operators; multi-person decision making	2011
389	Merigó, J. M.	Fuzzy multi-person decision making with fuzzy probabilistic aggregation operators	International Journal of Fuzzy Systems	Multi-person decision making; Fuzzy probabilistic OWA	2011
403	Zeng, S. Z.; Su W.	Linguistic induced generalized aggregation distance operators and their application to decision making	Economic Computation and Economic Cybernetics Studies and Research	Linguistic variables; OWA operator; distance measure; decision making; human resource management	2012
446	Zeng, S.; Su, W.; Le, A.	Fuzzy generalized ordered weighted averaging distance operator and its application to decision making	International Journal of Fuzzy Systems	FGOWADO; Hamming distance, fuzzy Euclidean OWA distance	2012
488	Merigó, J. M.; Xu, Y.; Zeng, S.	Group decision making with distance measures and probabilistic information	Knowledge-based Systems	Decision making; selection of policies; probability; Hamming distance; aggregating operators	2013
504	Zeng, S.; Merigó, J. M.; Su, W.	The uncertain probabilistic OWA distance operator and its application in group decision	Applied Mathematical Modelling	Probability; OWA operator; distance measures; uncertainty;	2013

		making		group decision making	
527	Su, W.; Li, W.; Zeng, S.	Atanassov's intuitionistic linguistic ordered weighted averaging distance operator and its application to decision making	Journal of Intelligent & Fuzzy Systems	Distance measures, OWA operator, Atanassov's intuitionistic linguistic variables, multi-person decision making	2014

4.5 Conclusion

This chapter has provided an overview of development of OWA models from the first conceptualization to 2014, describing the dominant direction in the OWA literature. It focused on the dominant direction rather than describing the several areas of OWA applications. Although it focuses on the dominant direction rather than the various areas of application of the OWA, this chapter identifies, within the dominant direction, some sub areas of research that are strongly represented within the OWA CPM results and, for this reason, can be expected to be exploited further by researchers in future developments of this discipline. The model selected for this thesis belongs to one of the two main streams identified. The application proposed in this thesis and presented in Chapter 5, expands the field of analysis that could benefit from OWA insights. So far, the OWA has not been applied to rank patent network citations, or to study indirect ties in networks. Thus, this thesis represents a first attempt to bridge the OWA and SNA fields.

Chapter 5. Patent citation networks: SNA and OWA applications

5.1. Introduction

This thesis investigates an innovative sector, the renewable energy industry. The topic of the renewable energy industry was chosen because it is a young sector, characterized by growing patenting activity since 2000. It is attracting interest from governments since it is seen as playing an important role in national economies (Bergmann et al., 2006). Investment in the renewable energy industry is growing at a fast pace, addressing environmental concerns in developed countries and presenting both challenges and opportunities for emerging countries. It is having an impact also on policy design (Wiser and Pickle, 1998; Inderst et al., 2012). For these reasons it is reasonable to believe that understanding the knowledge dynamics in the renewable industry is very important.

In selecting the young and innovative renewable energy sector, the decision to collect data over the last 13 years (2000-2013), has seemed a reasonable length of time. First because only over the last 10 years has this industry received considerable attention from governments and industry, and as a consequence the research and development received a boost. If another industry, such as biotechnology or nanotechnology would had be chosen, where patenting activity is much more rapid, the last 10 years could not be consider equally valuable.

The initial dataset of 53 European patents shows the market of the renewable energy in 2000 characterised mainly by Japanese and US multinational corporations such as Canon KK, Sharp and Kaneka Corporation, Evergreen Solar Inc., Rite Hite Holding, with few European companies such as the French Clipsol and English Electrical Valve and a few private inventors.

Chapter 5 presents the results of the SNA and OWA application conducted on the first 53 patents published in Europe in 2000 (Table 5.1), 37 of which were cited by other patents. The thesis focuses on these 37 patents and their corresponding networks, thus P1 (patent 1) is related to NP1 that is the network of citations constructed using P1 as the endpoint node, P2 has no network (no citations) and is not part of the 37, P3 to NP3, P4 to NP4, P5 to NP5, P6 to NP6, etc. Table 5.3 lists the 53 patents and their forward citations.

To compare the SNA and OWA results about each original patent, each NP has been considered as an autonomous network. The OWA score allows ranking the original patents considering the forwards distributions received by each one, for this reason we need a comparable SNA ranking regarding each original patent and not any other nodes along the NP.

The SNA of the 37 NP is inevitably long and consists of repeating the analysis on each NP. In Section 5.3, only the SNA results for NP3, NP14 and NP45 are presented. These three networks are selected as they are good examples of a small (NP14), a medium (NP3) and a large (NP45) network, and because they all show a citations distribution in line with the OWA orness level applied in this thesis. The other networks and the corresponding analyses are presented in the Appendix Chapter 5.

Table 5.1. Characteristics of the 53 European patents

Patents	Title	Owner
P1	Photovoltaic module	Kaneka Corporation (JP)
P2	Vented cavity radiant barrier assembly and method	Powerlight Corporation (US)
P3	Method of fabricating thin-film photovoltaic module	Kaneka Corporation (JP)
P4	Solar cell module and power generation apparatus	Canon KK (JP)

P5	Solar cell with a protection diode and its manufacturing method	Angewandte Solarenergie Gmbh (DE)
P6	Manufacturing method for a solar cell having a protection diode	English Electric Valve LTD (GB)
P7	Device for fixing a glass panel to a support at the side of a building	Dorma Gmbh & Co (DE)
P8	Fixing system for plate-shaped components	Lafarge braas roofing accessor (DE)
P9	Photovoltaic power generation apparatus and control method thereof	Canon KK (JP)
P10	Solar cell module and solar cell panel	Sharp KK (JP)
P11	Installation structure of solar cell module array, installation method of solar cell module, and sunlight power generation system	Canon KK (JP)
P12	Solar collector made of fibres	Private inventors (DE)
P13	Covering element for roofs for solar energy collection	Erlus Baustoffwerke (DE)
P14	Method of encapsulating a photovoltaic module by an encapsulating material	Kaneka Corporation (JP)
P15	Reverse biasing apparatus for solar battery module	Kaneka Corporation (JP)
P16	Circuit arrangement for power generation with solar cells	Angewandte Solarenergie - ASE Gmbh Produktzentrum Phototronics
P17	Solar cell module solar cell-bearing roof and solar cell power generation system	Canon KK (JP)
P18	Solar module adapted to be installed on vehicles and method of its fabrication	Assignee Webasto Vehicle Systems International Gmbh (DE)
P19	Assembly with photovoltaic panel for a roof	Ubbink Nederland
P20	Process for mounting solar collector panels	Clipsol (FR)
P21	Burner with helicoidal path for combustion products	Private inventor (CH)
P22	Method for thermal utilization of spent grain	Braun Union Osterreich
P23	Solar cell module	Kaneka Corporation (JP)
P24	Fixing device for solar modules	Private inventor (DE)
P25	Solar cell roof tile and method of forming same	Evergreen Solar Inc. (US)
P26	Electrostatic derivation for solar cells	Dornier Gmbh
P27	Fastening system for a panel-shaped building element	Lafarge Braas Roofing Accessor (DE)
P28	Method of manufacturing a tin film solar module and an apparatus for cutting	Antec Solar Gmbh
P29	Photovoltaic element and production method therefor	Canon KK (JP)
P30	Solar cell module, solar cell module string, solar cell system, and method for supervising said solar	Canon KK (JP)

	cell module or solar cell module string	
P31	Solar battery modules, installation method thereof, and solar power generator using such modules	Canon KK (JP)
P32	Processing method and apparatus for designing installation layout of solar cell modules in photovoltaic power generation system and computer program product storing the processing method	Canon KK (JP)
P33	Building element for roof and/or façade covering and its manufacturing method	Private inventor (CH)
P34	Combined photovoltaic array and RF reflector	TRW Corporation (US)
P35	Solar generator with solar cells fixed in series on a supporting frame	Private inventor (DE)
P36	Structure and method for installing photovoltaic module	Kaneka Corporation (JP)
P37	Photovoltaic generation system, wiring apparatus for photovoltaic generation system, and wiring structure therefor	Kaneka Corporation (JP)
P38	Solar power source with textured solar concentrator	Hughed Electronics Corporation (US)
P39	Photovoltaic solar module in a plate form	Pilkington Solar International Gmbh
P40	Photovoltaic module and power generation system	Kaneka Corporation (JP)
P41	Solar cell roof structure and construction method thereof	Kaneka Corporation (JP)
P42	Cover system for arranging on a surface one or more solar elements such as solar panels and/or solar thermal collectors	Cooperatief advise en Onderzoek (NL)
P43	Photovoltaic module framing system with integral electrical raceways	BP Solarex (US)
P44	Solar cell with a protection diode	English Electric Valve (GB)
P45	A terminal box device, and a solar panel and terminal box device assembly	Sumitomo Wiring Systems (JP)
P46	Wind-driven vessel	Imura Kaku (JP)
P47	Solid state electric generator using radionuclide-induced exciton production	British Nuclear Fuels (GB)
P48	Buoyant platform for radiant energy collecting apparatus	Private inventor (AU)
P49	Solar cell module	TDK Corporation (JP)
P50	Roller sealing apparatus for forming a weather seal between a vehicle and a loading dock or the like	Rite Hite Holding Corporation (US)
P51	Solar cell having an integral monolithically grown bypass diode	Techstar Power Systems (US)
P52	Frame made for shaped sections and designed for	Enecolo AG (CH)

	plate-like elements, and array of several such frames	
P53	Device for fixing a glass panel to a support at the side of a building	Dorma Gmbh & Co (DE)

5.2 Data

5.2.1. The renewable energy industry

The dataset used in this work has typical characteristics due to the way data were retrieved from the original source, the EPO PATSTAT. It contains raw data organized in a My-SQL database consisting of 20 tables with rich bibliographic data and citations ties among 70 million applications, for more than 80 countries. The final dataset comprises direct and indirect citations to original patents counted and allocated at the corresponding place. Following studies presented in Chapter 2 about the citation distributions in citation network, we assume the citations distribution within our dataset follows a power law, with few exceptions. No other structural feature emerges.

The sector was identified using the six IPC codes belonging to the patents dealing with wind, solar, geothermal, ocean, biomass and waste (Table 5.2). These categories account for the three generations of technologies that can be distinguished within that sector (International Energy Agency, 2006; Johnstone et al., 2010). The IPC is a hierarchical classification system applied to published patent documents. All patents published in 2000 in the EU, related to the renewable energy industry were gathered. The patenting rate within the renewable energy technologies surged in the 2000s (Glachant et al., 2008). Patents published in 2000 are related more to solar technologies than inventions dealing with more recent technologies such as biomass energy.

Table 5.2. IPC codes for the renewable energy sector

Renewable energy technologies	IPC codes – Class	Sub-Class
Wind	F03D	1/00-06
	F03D	3/00-06
	F03D	5/00-06
	F03D	7/00-06
	F03D	9/00-02
	F03D	11/00-04
	B60L	8/00
	B63H	13/00
Solar	F03G	6/00-08
	F24J	2/00-54
	F25B	27/00B
	F26B	3/28
	H01L	31/042
	H02N	6/00
	E04D	13/18
	B60L	8/00
Geothermal	F24J	3/00-08
	F03G	4/00-06
	H02N	10/00
Ocean	F03B	13/12-24
	F03G	7/05
	F03G	7/04
	F03B	7/00
Biomass	C10L	5/42-44
	F02B	43/08
	C10L	1/14
	B01J	41/16
Waste	C10L	5/46-48
	F25B	27/02
	F02G	5/00-04
	F23G	5/46
	F012K	25/14
	C10J	3/86
	F23G	7/10
	H01M	8/06

Table 5.3. Number of patent citations related the 53 European patents

Patents	1st place	2nd place	3rd place	4th place	5th place	6th place	7th place	8th place	9th place	10th place
P1	4	0	0	0	0	0	0	0	0	0
P2	0	0	0	0	0	0	0	0	0	0
P3	10	62	21	4	1	0	0	0	0	0
P4	9	6	1	1	0	0	0	0	0	0
P5	8	27	38	30	13	0	0	0	0	0
P6	2	6	1	0	0	0	0	0	0	0
P7	0	0	0	0	0	0	0	0	0	0
P8	0	0	0	0	0	0	0	0	0	0
P9	0	0	0	0	0	0	0	0	0	0
P10	9	24	35	20	19	5	2	1	0	9
P11	3	6	14	56	45	19	10	5	3	0
P12	7	71	130	31	14	13	15	7	4	1
P13	0	0	0	0	0	0	0	0	0	0
P14	4	3	0	0	0	0	0	0	0	0
P15	1	0	0	0	0	0	0	0	0	0
P16	5	22	10	6	0	0	0	0	0	0
P17	5	4	7	5	0	0	0	0	0	0
P18	6	3	0	0	0	0	0	0	0	0
P19	8	7	5	0	0	0	0	0	0	0
P20	2	10	0	0	0	0	0	0	0	0
P21	1	2	0	0	0	0	0	0	0	0
P22	6	1	0	0	0	0	0	0	0	0
P23	2	9	2	0	0	0	0	0	0	0
P24	0	0	0	0	0	0	0	0	0	0
P25	0	0	0	0	0	0	0	0	0	0
P26	0	0	0	0	0	0	0	0	0	0
P27	9	16	2	0	0	0	0	0	0	0
P28	0	0	0	0	0	0	0	0	0	0
P29	4	6	2	0	0	0	0	0	0	0
P30	5	8	0	0	0	0	0	0	0	0
P31	0	0	0	0	0	0	0	0	0	0
P32	9	3	0	0	0	0	0	0	0	0
P33	2	2	0	0	0	0	0	0	0	0
P34	2	0	0	0	0	0	0	0	0	0
P35	6	10	0	0	0	0	0	0	0	0
P36	3	5	32	32	2	1	0	0	0	0
P37	7	2	0	0	0	0	0	0	0	0
P38	0	0	0	0	0	0	0	0	0	0
P39	18	66	52	52	17	15	10	4	2	0
P40	8	19	13	9	4	2	3	4	1	1
P41	7	53	60	38	13	16	7	3	1	0
P42	40	93	69	32	26	12	13	4	2	2
P43	17	104	124	97	33	11	1	1	0	0

P44	3	6	9	0	0	0	0	0	0	0
P45	35	135	103	31	17	16	7	2	1	0
P46	2	0	0	0	0	0	0	0	0	0
P47	0	0	0	0	0	0	0	0	0	0
P48	0	0	0	0	0	0	0	0	0	0
P49	7	18	32	27	19	7	3	1	0	0
P50	0	0	0	0	0	0	0	0	0	0
P51	0	0	0	0	0	0	0	0	0	0
P52	1	0	0	0	0	0	0	0	0	0
P53	0	0	0	0	0	0	0	0	0	0

5.2.2. Characteristics of the data

To analyse a citation network requires relational data, that is, ‘Citing’ and ‘Cited’ documents. The data are original in being derived from an iterative process to retrieve all citations received (forward citations) by all the patents in each place. Thus, from the original 53 EU published in 2000 in the renewable energy industry we retrieved the forward citations, then we retrieved the forward citations for patents published in 2001 and so on, up to 2013. Note that the number of forward citations follows a scale-free distribution, that is, a small number of patents account for most of the ties and encounter several places of indirect citations, while the majority of patents have just a few forward citations. We retrieved several indirect citations for each patent.

The EPO PATSTAT database contains raw data organized in a My-SQL database consisting of 20 tables with rich bibliographic data and citations ties among 70 million applications, for more than 80 countries. To extract our data, we query 4 tables linked by the key application identification. This is the application number that identifies univocally each patent.

1) The first step consists of retrieving from the database the application id (appln_id) identifying all patents published in 2000 with one of the IPC codes identifying the renewable energy sector. This information is in table 1 and 9 of the database (tls201_appln; tls209_appln_ipc);

2) The second step consists of retrieving from table 11 (tls_211_pat_publn) the patent publication identification corresponding to each application id retrieved in the first step;

3) The third step consists of retrieving from table 12 (tls12_citation) patents published after 2000 citing patents published in 2000 within the renewable energy industry. This step is replicated iteratively until zero citations are found.

The final dataset comprises direct and indirect citations to original patents counted and allocated at the corresponding place.

5.3. SNA results

The vertices in each network are identified using Pajek software, and numbered 1 to *n*, ordered chronologically from oldest to newest. Thus, vertex 1 in each NP, is the patent that is the object of analysis (P3 in the first section, P14 in the second, and so on). The last table (Table 5.12) in each section reports the result of the SPC. The objective of the SPC algorithm is to highlight the 'technological trajectory', and the corresponding figure (Figure 5.6) shows it as the most important path. The SPC table shows only those patents belonging to the highlighted trajectory. Each patent is labelled according to the patent publication date and number (i.e. 20001220-00495792). The publication number classifies the patent in the EPO database and corresponds with a publication number and authority label indicating the office publishing the patent, for example, EU for European, US for

American, WO for patents published simultaneously in several countries, FR for France or IT for Italy. This provides information on the most active countries in this sector. In a few cases the patent title is provided in the original language only - German, French or Italian.

For complex networks with very numerous nodes, the corresponding tables present only the first 10 results. In the section related to in-degree centrality, which provides information on the number of direct citations received, only the most cited patents are described; this applies also to the results for closeness centrality. In the hubs and authorities section, the first five patents are described. In some cases, the same patent might appear in more than one network; in these cases, it is described in each of the networks in which it appears because the aim is to present a description of each individual network in a separate section.

Before showing the SNA and OWA results, we compare the two rankings obtained (Table 5.6) by means of the Wilcoxon test (Table 5.4 and 5.5), which confirms that the two ranking differs substantially. In comparing the two rankings we use four decimals for both scores. In the figures and the other tables we will show only the first two.

Table 5.4. Wilcoxon signed ranks test

		N	Mean Rank	Sum of Ranks
SNA-OWA	Negative ranks SNA<OWA	33	21.52	710.00
	Positive Ranks SNA>OWA	5	6.20	31.00
	Ties SNA=OWA	15		
	Total	53		

Table 5.5. Test statistics

Test statistics	SNA-OWA
Z	-4.924[a]
Asymp. Sig. (2-tailed)	.000
a. Based on positive ranks	

Table 5.6. OWA score vs authority weights

Patents	OWA score	Authority weights	Patents	OWA score	Authority weights	Patents	OWA score	Authority weights
P1	1.0545	1	P24	0	0	P47	0	0
P2	0	0	P25	0	0	P48	0	0
P3	21.3036	0.0627	P26	0	0	P49	18.4672	0
P4	3.5018	1	P27	5.8054	0.0022	P50	0	0
P5	20.72	0.1636	P28	0	0	P51	0	0
P6	2.0072	0.0184	P29	2.4327	1	P52	0.2636	1
P7	0	0	P30	2.8454	0	P53	0	0
P8	0	0	P31	0	0			
P9	0	0	P32	2.8145	1			
P10	20.2890	0	P33	0.8218	0.7071			
P11	27.5272	0	P34	0.5272	1			
P12	53.8927	0	P35	3.5199	1			
P13	0	0	P36	14.4254	0			
P14	1.4963	1	P37	2.1399	1			
P15	0.2636	1	P38	0	0			
P16	8.6309	0	P39	37.74	0			
P17	3.6945	0.02	P40	10.0818	0			
P18	2.0236	0.9732	P41	32.9181	0			
P19	3.7945	1	P42	48.2781	0			
P20	2.9309	0	P43	67.1690	0			
P21	0.6745	0.0078	P44	3.6490	0			
P22	1.7290	0.9820	P45	62.4599	0			
P23	2.9290	0	P46	0.5272	1			

As indicated before, we now explain three networks in different size of medium (NP3), small (NP14) and large (NP45), details of other networks are given in Appendix Chapter 5.

<u>Example of a medium size network NP3</u>

P3 is the European patent published by the Japanese Kaneka Corporation, under the title 'Method of fabricating thin-film photovoltaic module'. The characteristics of NP3 are given in Table 5.7.NP3. It includes one loop which was removed before calculating the network measures. Although a citations network is generally acyclical, there can be loops that violate this condition. This can happen in a patent citation network, for example when one of the three patent offices (European, US and Japan) processes applications more quickly is than another.

Table 5.7.NP3. Characteristics

Number of vertices (n)	**99**
	Arcs
Total number of lines	116
Number of loops	1
Number of multiple lines	0
Density [loops allowed]	0.01
Average degree	2.34

<u>*In-degree centrality* (Figure 5.1.NP3, Table 5.8.NP3)</u> - Figure 5.1.NP3 depicts NP3 according to the in-degree centrality measure, and the corresponding values are displayed in Table 5.7. According to in-degree centrality, the first patent, the most cited, in NP3 is vertex 3, while P3 occupies 4th position. The most cited patent was published in the US in 2007 with the title 'Method of manufacturing thin film photovoltaic modules', the applicant is the BP Corporation North America Inc.

Table 5.8.NP3. Top 10 in-degree and out-degree centrality values of NP3

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	3	27	20070821-62398637	76	5	20120306-75837741
2	6	17	20080515-29436452	41	4	20101216-75416781
3	4	12	20071221-00078925	95	3	20121218-74910580
4	1 (P3)	10	20001220-00495792	60	2	20110621-71003687
5	2	7	20051215-07096762	6	2	20080515-29436452
6	60	5	20110621-71003687	27	2	20100602-73385677
7	13	4	20090813-70444497	24	2	20100311-72844604
8	18	4	20091231-72194927	90	2	20120904-72749014
9	8	4	20090129-69275079	44	2	20101230-75279517
10	7	3	20080611-19246728	42	2	20101216-75427617

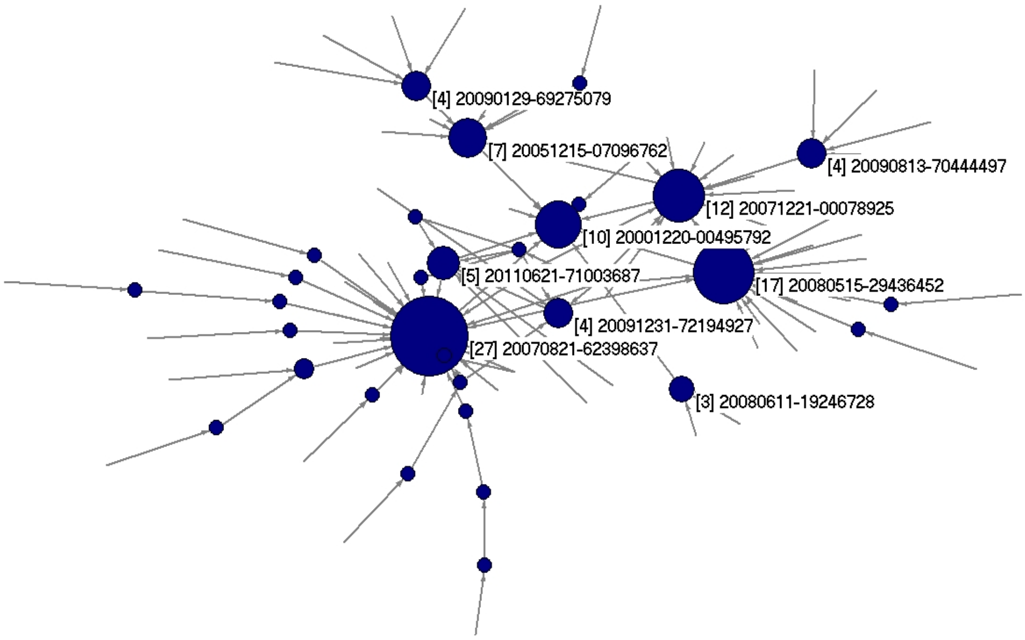

Figure 5.1.NP3. In-degree centrality of NP3

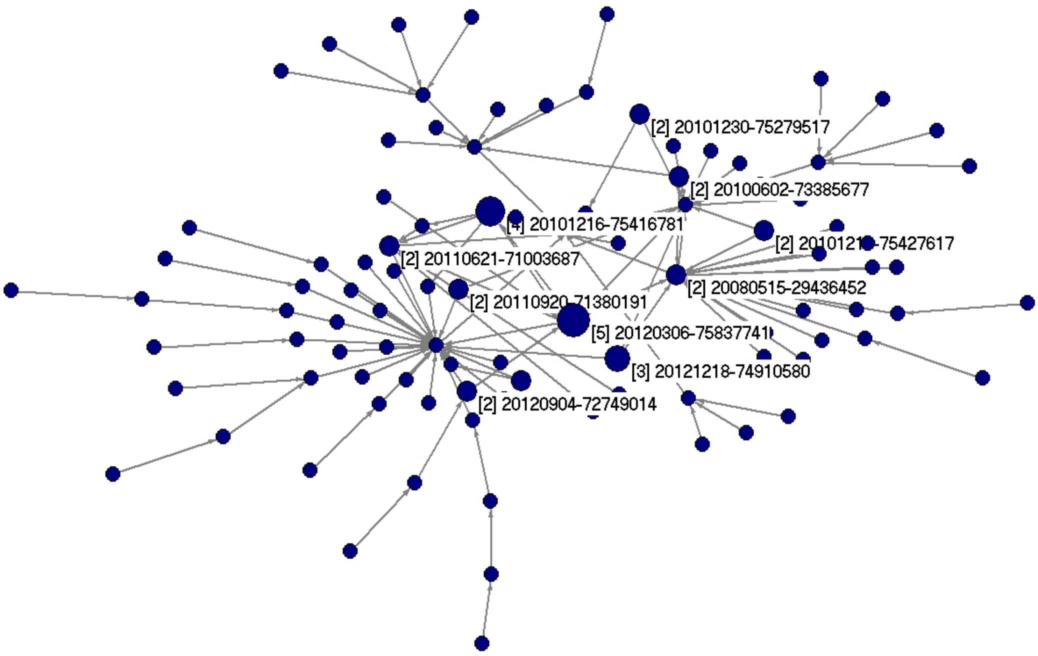

Figure 5.2.NP3. Out-degree centrality of NP3

Closeness centrality (Figure 5.3.NP3; Table 5.9.NP3) – P3 is first among the top 10 patents according to the closeness centrality measure. This means that it is relatively close to all others. The concept is more intuitively explained by Figure 5.3.NP3, which shows P3 lying at the centre of the surrounding clusters.

Table 5.9.NP3. Top 10 closeness centrality measures of NP3

Rank	**Vertex**	**Value**	**Id (Label)**
1	1 (P3)	0.45	20001220-00495792
2	3	0.43	20070821-62398637
3	76	0.38	20120306-75837741
4	6	0.38	20080515-29436452
5	60	0.37	20110621-71003687
6	95	0.37	20121218-74910580
7	4	0.37	20071221-00078925
8	67	0.35	20110920-71380191
9	2	0.34	20051215-07096762
10	7	0.32	20080611-19246728

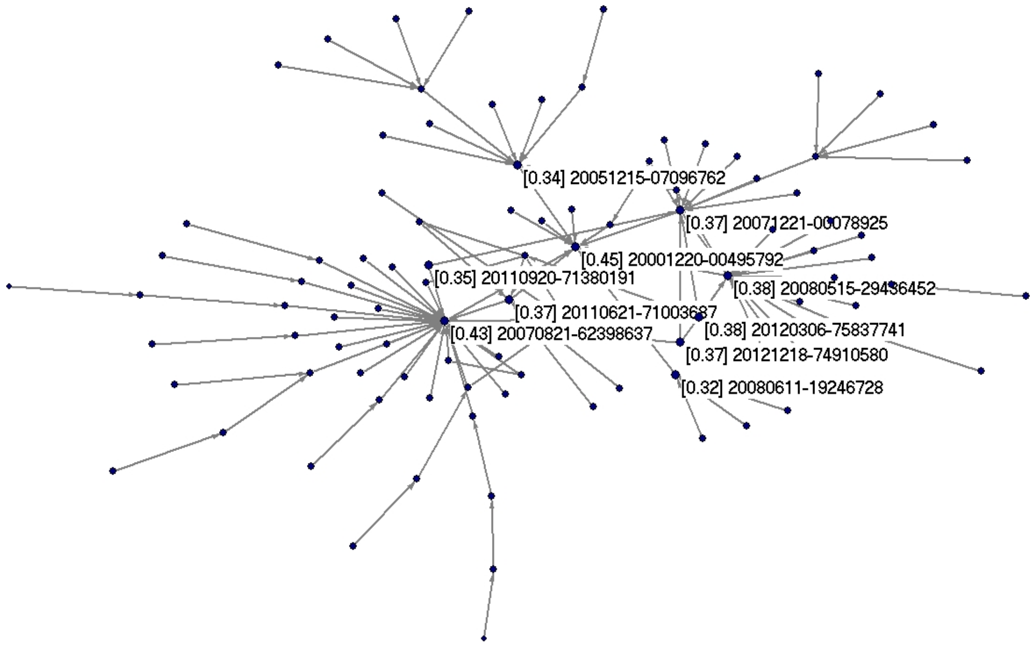

Figure 5.3.NP3. Closeness centrality of NP3

Authority weights (Figure 5.4.NP3, Table 5.10.NP3) – show the results of the hubs and authorities algorithm. They identify the first ten most authoritative patents and their best developments.

P3 occupies fifth place in the ranking:

- the most authoritative patent (vertex 3) is also the most cited according to the in-degree centrality;
- the second most authoritative patent (vertex 6) was published in 2008, the applicant is a UK company, Exitech Ltd, a manufacturer of high-power pulsed laser-based systems for industrial materials processing applications. The title of the patent is 'Method and apparatus for laser beam alignment for solar panel scribing';
- the third (vertex 4) also belongs to Exitech and was published in 2007 and deals with a similar technology. The title is 'Process for laser scribing'.

- the fourth most authoritative patent (vertex 18) was published in 2009 in the US, the owner is the company Applied Material Inc. It deals with technology similar to the previous three patents, the title is 'Dynamic scribing alignment for laser scribing, welding or any patterning system'.
- the fifth is P3.

Table 5.10.NP3. The authority patents of NP3

Rank	Vertex	Value	Id (Label)
1	3	0.94	20070821-62398637
2	6	0.23	20080515-29436452
3	4	0.23	20071221-00078925
4	18	0.10	20091231-72194927
5	1 (P3)	0.06	20001220-00495792
6	41	0.05	20101216-75416781
7	47	0.03	20110208-71008390
8	2	0.01	20051215-07096762

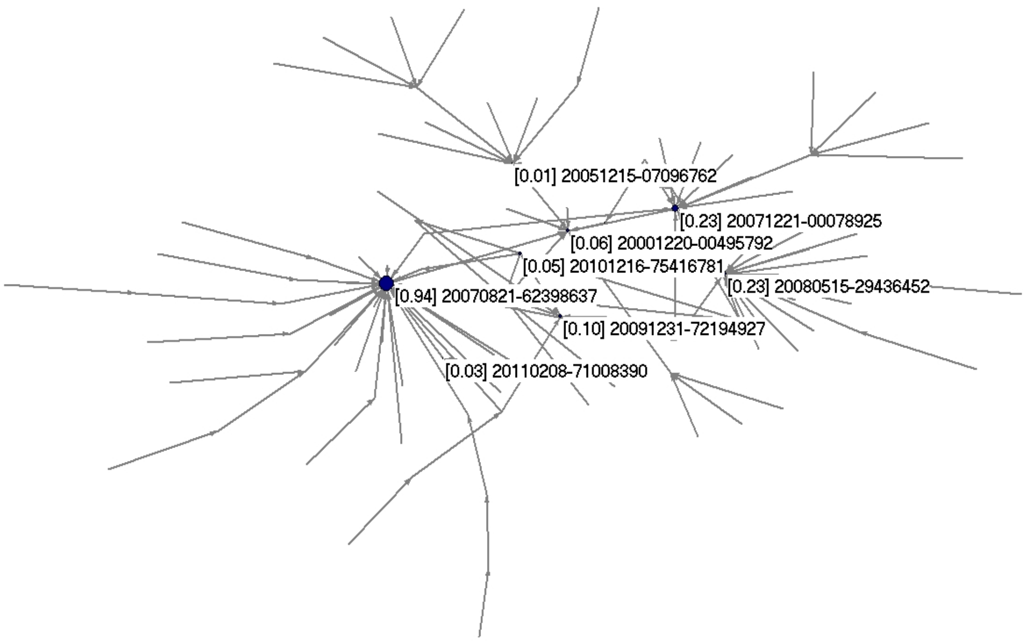

Figure 5.4.NP3. The authority patents of NP3

<u>*Hub weights (Figure 5.5.NP3; Table 5.10.NP3)*</u> - Table 5.10.NP3 shows the 10 best developments of the most authoritative patents. These are the most recent patents, which were published mostly in 2011 and 2012. Focusing on the first five hubs:

1. the first best development (vertex 76) is the US patent owned by the company Applied Materials Inc., with the title 'Method and related systems for thin film laser scribing devices';
2. the second hub (vertex 95) is the US patent owned by the company Applied Materials Inc., with the title 'Process to remove metal contamination on a glass substrate';
3. the third hub (vertex 67) is the patent entitled 'Method and apparatus for forming the separating lines of a photovoltaic module with series-connected cells', published in 2009, owned by German inventor Walter Psyk;
4. the fourth patent (vertex 90) is the patent entitled 'Laser material removal methods and apparatus', owned by the company Applied Materials Inc.;
5. the fifth hub (vertex 60) is the patent entitled 'Process for laser scribing', published in US by the UK company, Exitech Ltd.

Table 5.11.NP3. Top 10 hub weights of NP3

Rank	Vertex	Value	Id (Label)
1	76	0.29	20120306-75837741
2	95	0.26	20121218-74910580
3	67	0.21	20110920-71380191
4	90	0.19	20120904-72749014
5	60	0.18	20110621-71003687
6	66	0.18	20110920-70963786
7	29	0.18	20100608-67399182
8	59	0.18	20110621-58817246
9	58	0.18	20110607-72844891
10	12	0.18	20090610-70400694

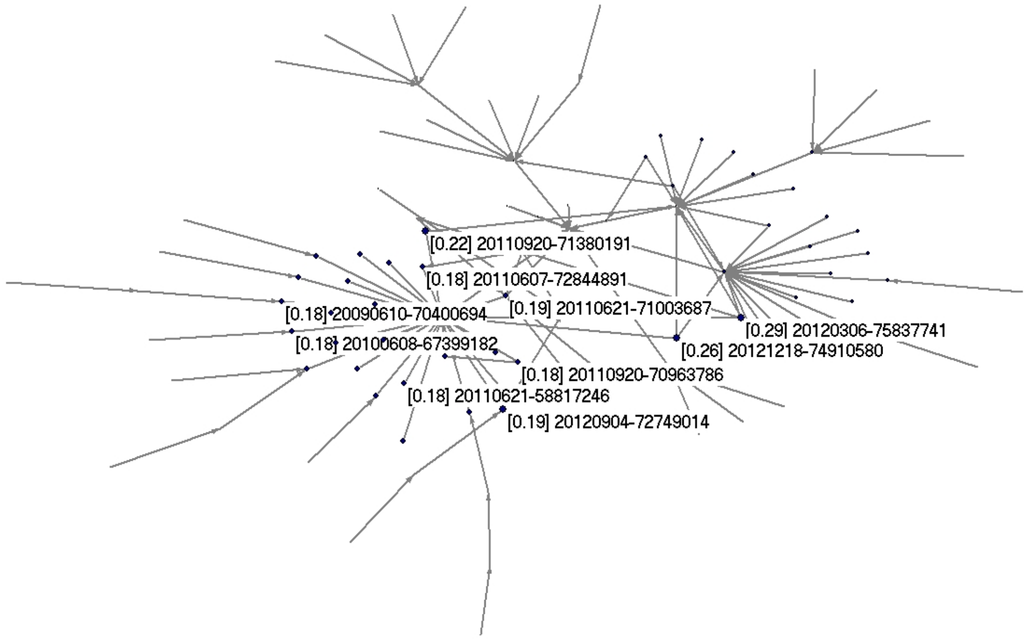

Figure 5.5.NP3. The hub patents of NP3

<u>*SPC (Figure 5.6.NP3; Table 5.12.NP3)*</u> - This section presents the results of the SPC algorithm. Figure 5.6.NP3 depicts the 'main path' emerging in NP3, it identifies seven patents that are listed in Table 5.12.NP3. According to the SPC results, the technological trajectory shows P3 as endpoint and vertex 76 as startpoint. It has been identified previously as the first best hub in the network. Along the trajectory there are five patents already described among the top authority patents or as their best developments (vertex 3, 60, 41, 76, 18, 34).

Table 5.12.NP3. Vertices on main path SPC [flow] of NP3

Rank	**Vertex**	**Cluster**	**Id (Label)**
1	1 (P3)	1	20001220-00495792
2	3	1	20070821-62398637
3	60	1	20110621-71003687
4	41	1	20101216-75416781
5	76	1	20120306-75837741
6	18	1	20091231-72194927
7	34	1	20101028-74934241

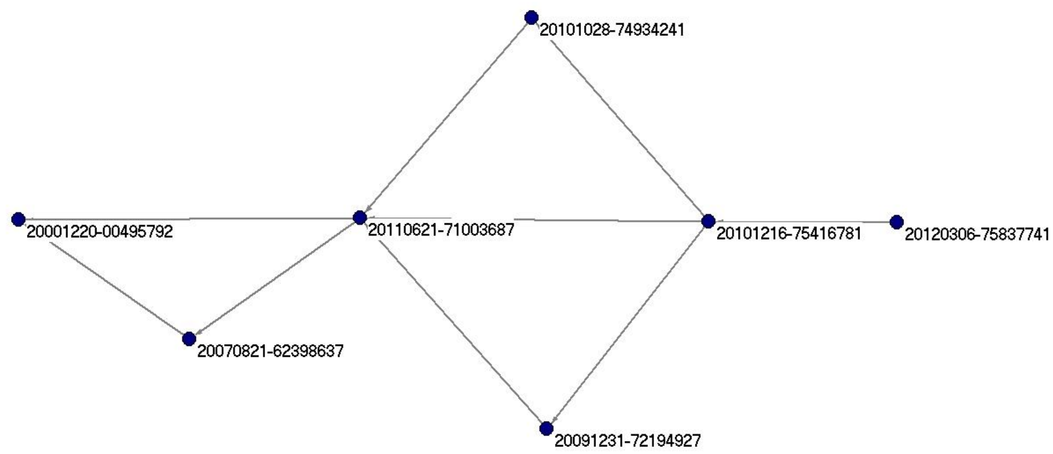

Figure 5.6.NP3. SPC of NP3

Example of a small network (NP14)

P14 was published in the EU in 2000 by the Japanese company, Kaneka Corporation. The title is 'Method of encapsulating a photovoltaic module by an encapsulating material' (H01L31/048; H01L31/18). NP14 is a small network made up by eight vertices and seven arcs.

Table 5.7.NP14. Characteristics

Number of vertices (n)	**8**
	Arcs
Total number of lines	7
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.10
Average degree	1.75

In-degree centrality (Figure 5.1.NP14; Table 5.8.NP14) – According to the in-degree centrality values, P14 the most cited patent, followed by only another one patent.

Table 5.8.NP14. In-degree and out-degree centrality values of NP14

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	1(P14)	4	20001213-18055210	3	1	20080521-19246695
2	3	3	20080521-19246695	8	1	20120801-76314683
3				7	1	20120605-73511557
4				6	1	20111004-67865767
5				5	1	20100526-71737519
6				4	1	20091022-70336773
7				2	1	20080220-00311734

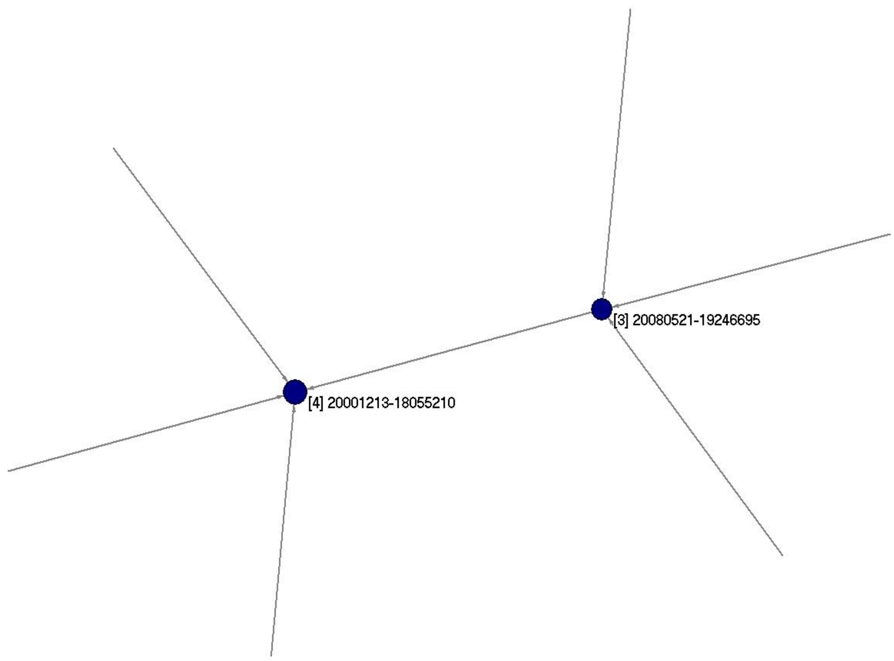

Figure 5.1.NP14. In-degree centrality of NP14

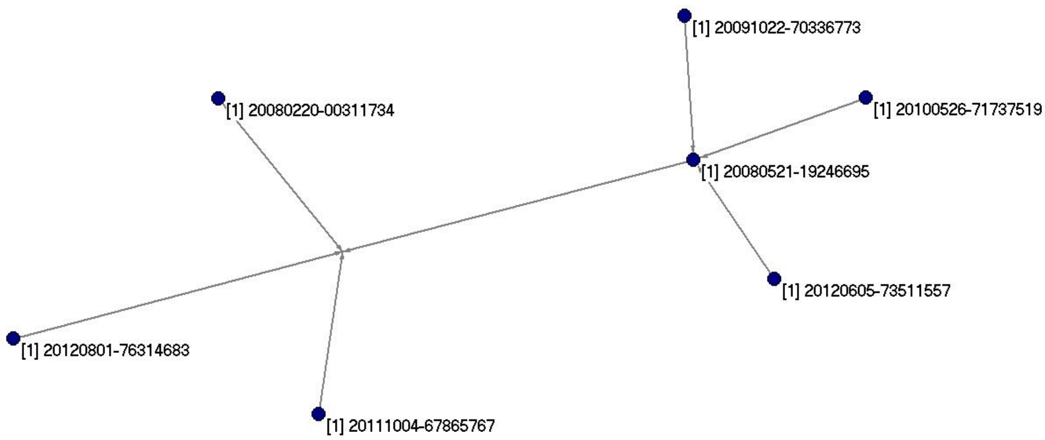

Figure 5.2.NP14. Out-degree centrality of NP14

Closeness centrality (Figure 5.3.NP14; Table 5.9.NP14) – P14 is ranked 1st in the 8 patents according to the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP14, which shows P14 lying at the centre of the surrounding clusters.

Table 5.9.NP14. Closeness centrality values of NP14

Rank	Vertex	Value	Id (Label)
1	1 (P14)	0.70	20001213-18055210
2	3	0.70	20080521-19246695
3	7	0.43	20120605-73511557
4	6	0.43	20111004-67865767
5	5	0.43	20100526-71737519
6	4	0.43	20091022-70336773
7	8	0.43	20120801-76314683
8	2	0.43	20080220-00311734

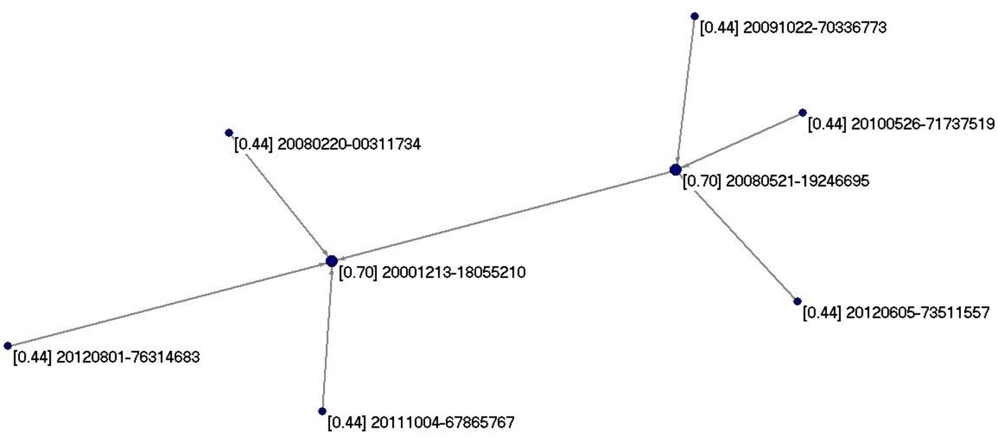

Figure 5.3.NP14. Closeness centrality of NP14

Authority weights (Figure 5.4.NP14; Table 5.10.NP14) – There are two authorities in NP14:

- P14 with the highest value (1);

- vertex 3, published in Europe by the Japanese NPC Corporation.

Table 5.10.NP14. The authority patents of NP14

Rank	Vertex	Value	Id (Label)
1	1 (P14)	1	20001213-18055210
2	3	0.02	20080521-19246695

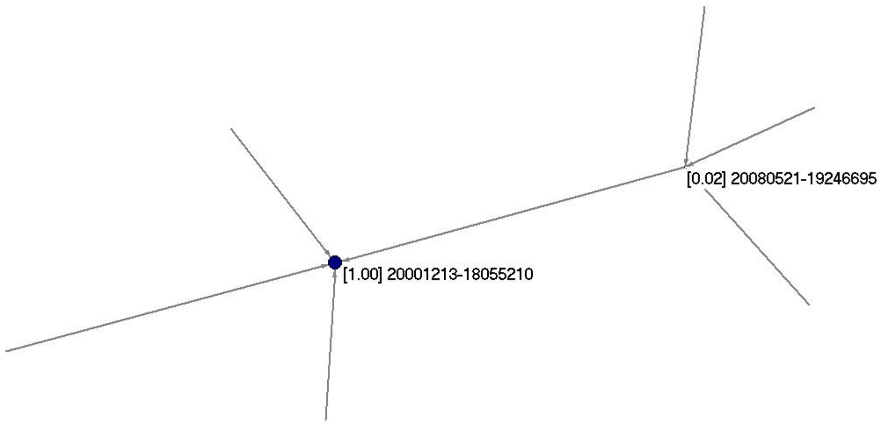

Figure 5.4.NP14. The authority patents of NP14

<u>*Hub weights (Figure 5.5.NP14; Table 5.11.NP14)*</u> – The top four best developments of the two core inventions previously identified are:

- vertex 3, the second authority;
- vertex 6, published in Europe by the NPC Corporation, with the title 'Laminating apparatus';
- vertex 2, published in the US by the NPC Corporation, with the title 'Laminating apparatus';
- vertex 8, published in Europe by Eurocopter Deutschland with the title 'Device and method for manufacturing of preimpregnated preform and multi-layer preimpregnated preform resulting from said method';

Table 5.11.NP14. The hub patents of NP14

Rank	Vertex	Value	Id (Label)
1	3	0.50	20080521-19246695
2	6	0.50	20111004-67865767
3	2	0.50	20080220-00311734
4	8	0.50	20120801-76314683
5	4	0.01	20091022-70336773
6	7	0.01	20120605-73511557
7	5	0.01	20100526-71737519

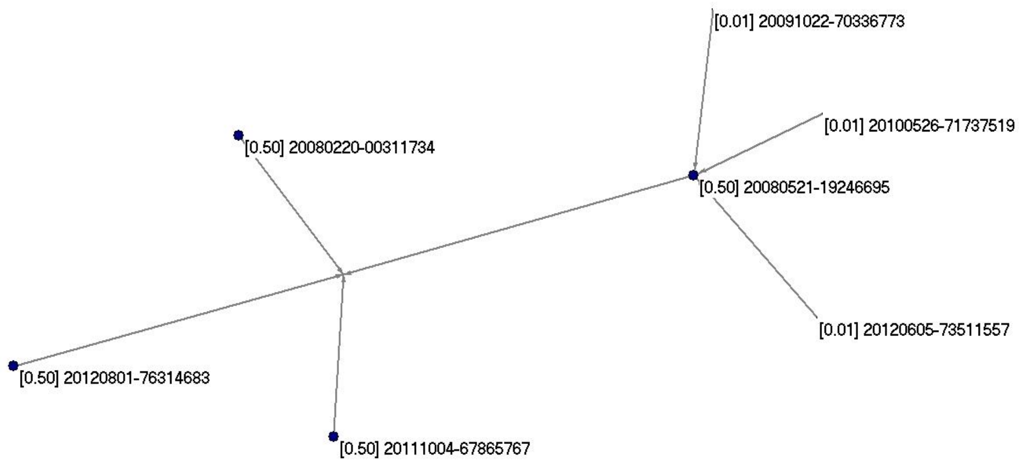

Figure 5.5.NP14. Hub patents of NP14

<u>*SPC (Figure 5.6.NP14; Table 5.12.NP14)*</u> – The technological trajectory comprises all eight patents, from P8 to the most recent vertex 7, a patent published in the US by Komax Holding, with the title 'Apparatus for laminating a solar module'.

Table 5.12.NP14. Vertices on main path SPC [flow] of NP14

Rank	Vertex	Cluster	Id (Label)
1	1 (P14)	1	20001213-18055210
2	2	1	20080220-00311734
3	3	1	20080521-19246695
4	4	1	20091022-70336773
5	5	1	20100526-71737519
6	6	1	20111004-67865767
7	7	1	20120605-73511557
8	8	1	20120801-76314683

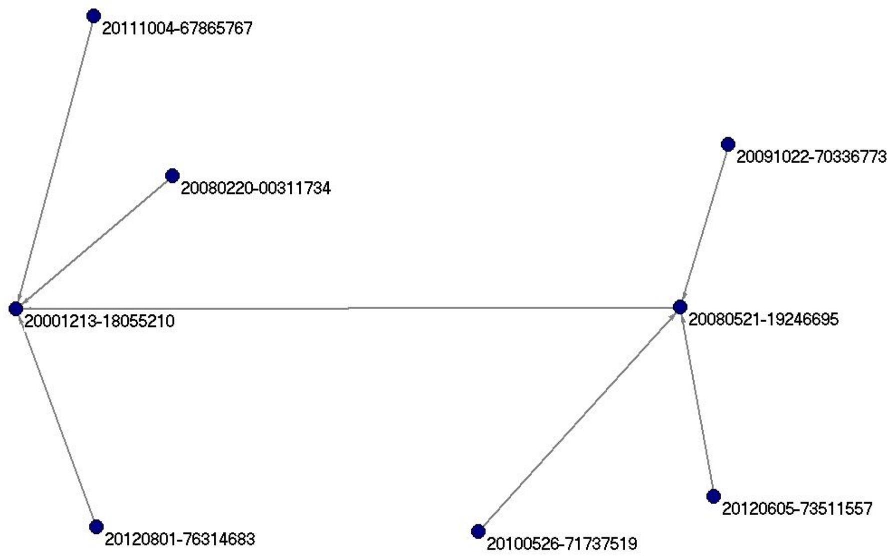

Figure 5.6.NP14 SPC of NP14

Example of a large network (NP45)

P45 is a European patent owned by the Japanese company Sumitomo Wiring Systems, with the title 'A terminal box device, and a solar panel and terminal box device assembly' (IPC: H01L31/02). NP45 characteristics are given in Table 5.7.NP45.

Table 5.7.NP45. Characteristics

Number of vertices (n)	**349**
	Arcs
Total number of lines	788
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.00
Average degree	4.51

In-degree centrality (Figure 5.1.NP45, Table 5.8.NP45) - According to the in-degree centrality values, P45 is the most cited patent in NP45, with 34 citations. The next most cited (vertex 3) is the patent owned by the German Tyco Electronics AMP GmbH, with the title in the original language 'Anschlussdose für ein Solarpaneel und Solarpaneel'.

Table 5.8.NP45. Top 10 in-degree and out-degree centrality values of NP45

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	1 (P45)	34	20000510-21333832	328	39	20121113-78039768
2	3	29	20040708-15789814	126	20	20100722-73856832
3	10	29	20060829-67365978	252	17	20120329-79407826
4	2	23	20040219-15789815	291	16	20120626-76379281
5	5	23	20050825-17082243	132	16	20100930-74621952
6	13	21	20061206-19090049	246	14	20120301-79199318
7	252	18	20120329-79407826	187	12	20110616-76868845
8	20	18	20071025-21524608	155	12	20110106-75606264
9	31	15	20080617-65252026	231	11	20120117-58857259
10	11	15	20061114-67365259	306	11	20120802-80362911

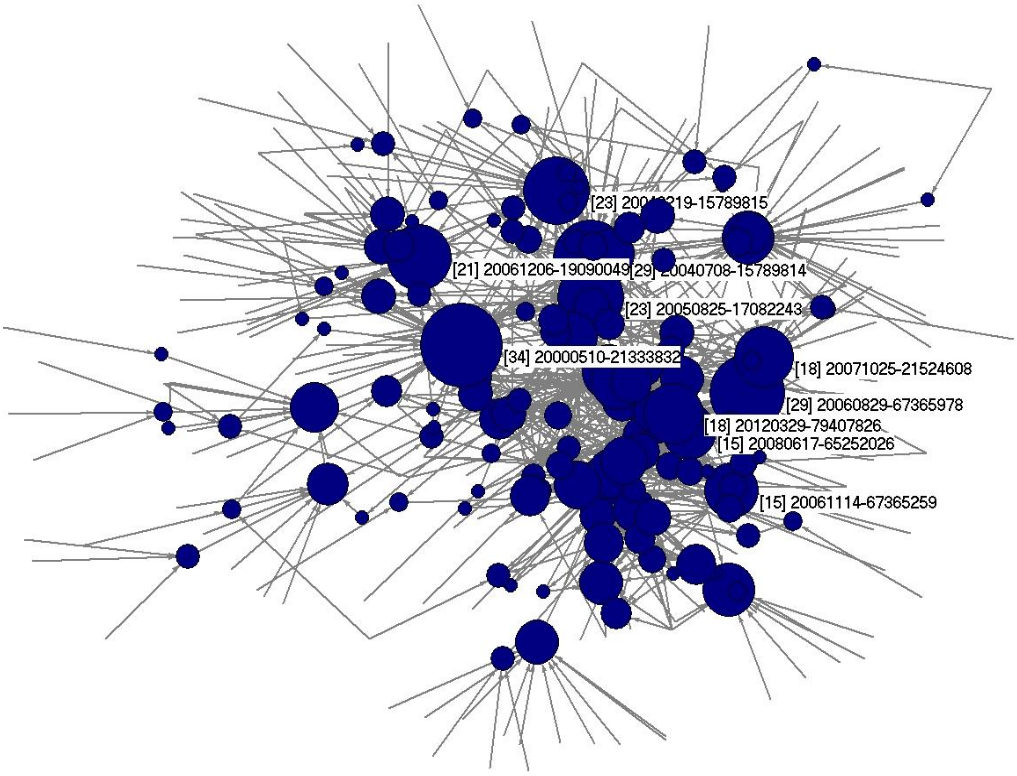

Figure 5.1.NP45. In-degree centrality of NP45

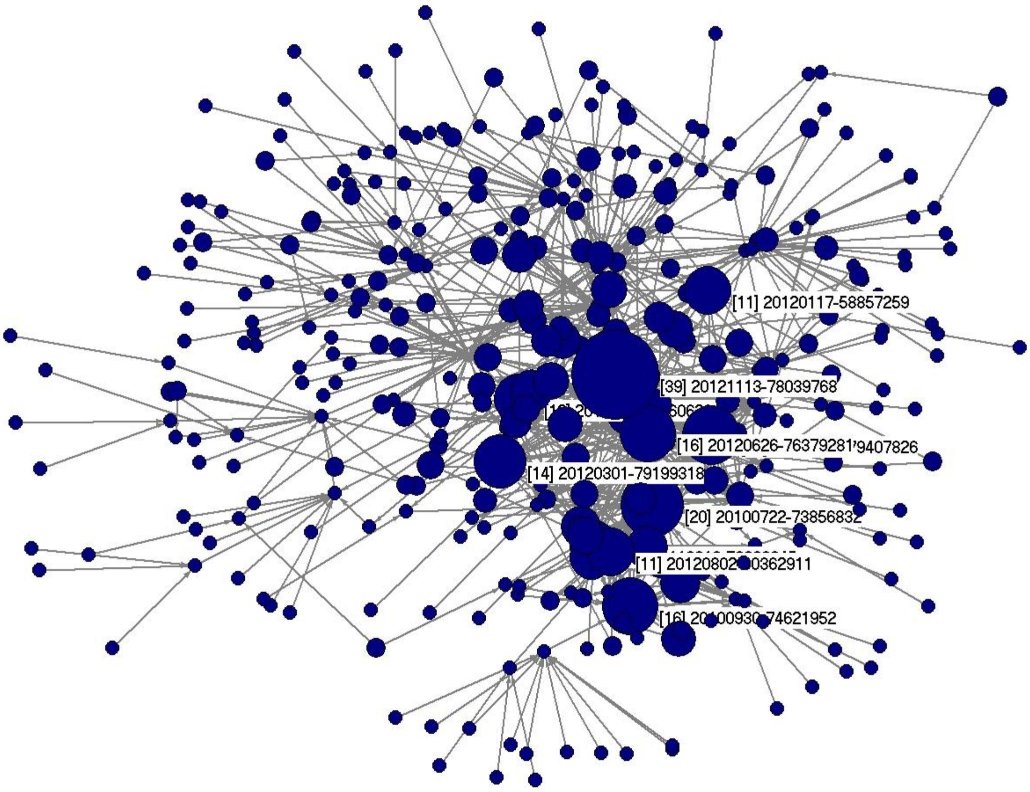

Figure 5.2.NP45. Out-degree centrality of NP45

<u>*Closeness centrality (Figure 5.3.NP45, Table 5.9.NP45)*</u> – Measured by closeness centrality, P45 is also the closest to the centre, followed by vertex 139 published 10 years later, owned by the German company, Weidmueller Interface, with the title 'Electrical connector arrangement for flat conductors'.

Table 5.9.NP45. Closeness centrality values of NP45

Rank	Vertex	Value	Id (Label)
1	1 (P45)	0.40	20000510-21333832
2	139	0.38	20101102-73155016
3	252	0.38	20120329-79407826
4	328	0.38	20121113-78039768
5	3	0.37	20040708-15789814
6	10	0.36	20060829-67365978
7	247	0.36	20120306-77243626
8	90	0.36	20100119-00673757
9	126	0.36	20100722-73856832
10	219	0.35	20111213-74322065

Figure 5.3.NP45. Closeness centrality of NP45

<u>*Authority weights (Figure 5.4.NP45, Table 5.10.NP45)*</u> – P45 is not an authority patent in NP45. The top five are:

- vertex 187, owned by the Samsung Corporation, with the title 'Power converting device for new renewable energy storage system';
- vertex 291, owned by five private inventors, with the title 'System and apparatus for interconnecting an array of power generating assemblies';
- vertex 232, owned by the Finnish ABB Group, with the title 'Method and arrangement in wind power plant';
- vertex 202, owned by the American Hamilton Sundstrand Corporation, with the title 'Multi-level parallel phase converter';
- vertex 126, owned by the American CertainTeed Corporation, with the title 'Photovoltaic roof covering'.

Table 5.10.NP45. The authority patents of NP45

Rank	Vertex	Value	Id (Label)
1	187	0.96	20110616-76868845
2	291	0.26	20120626-76379281
3	232	0.04	20120117-67868918
4	202	0.04	20110929-77632730
5	126	0.03	20100722-73856832
6	95	0.03	20100225-72682175
7	137	0.03	20101026-72030361
8	316	0.02	20120920-80743073
9	163	0.02	20110308-74930119
10	252	0.02	20120329-79407826

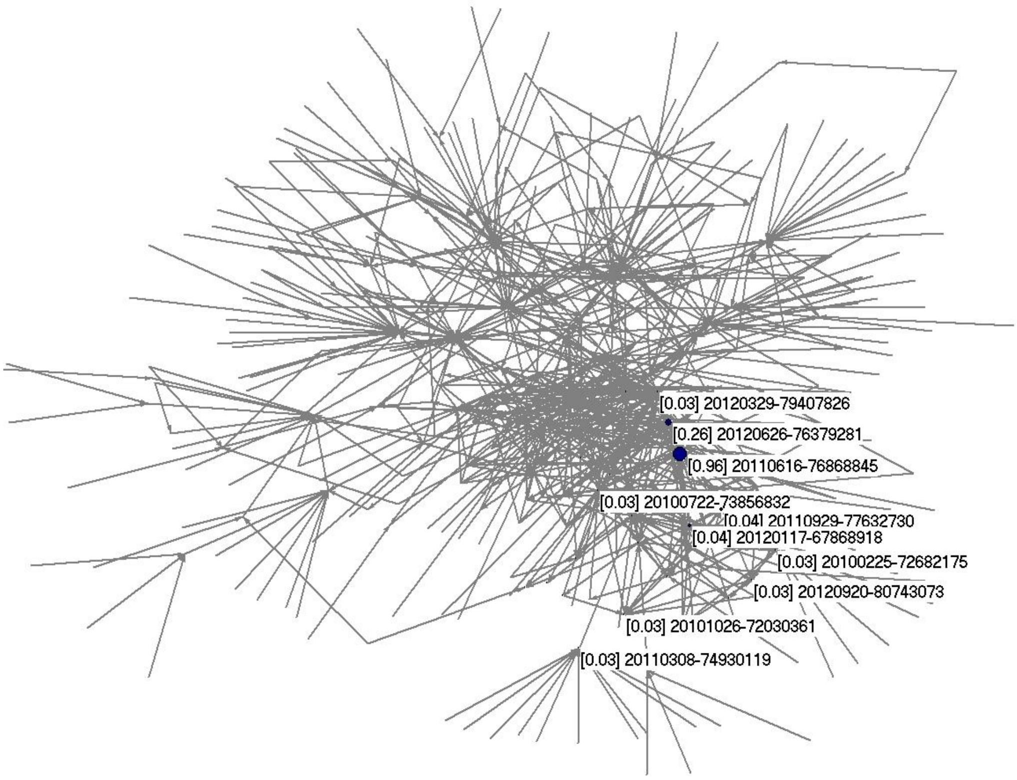

Figure 5.4.NP45. The authority patents of NP45

<u>Hub weights (Figure 5.5.NP45, Table 5.11.NP45)</u> – The first five best developments are:

- vertex 324, published in Germany by the German Siemens Corporation, with the title in the original language, 'Energiespeichervorrichtung, umfassend mehrere Speichermodule für elektrische Energie';

- vertex 296, published in the US by the German company Solar Technology, with the title ‘Bidirectional inverter for conversion between a direct current source and an alternating current grid’;
- vertex 119, published in the US by the American company Enphase Energy, with the title ‘Mounting rail and power distribution system for use in a photovoltaic system’;
- vertex 225, published in the US by a private inventor with the title ‘ Solar energy collection systems and method’;
- vertex 210 published in the US by the American General Electric, with the title ‘System and method for protection of a multilevel converter’.

Table 5.11.NP45. The hub patents of NP45

Rank	Vertex	Value	Id (Label)
1	324	0.62	20121031-80990903
2	296	0.62	20120710-78814954
3	119	0.40	20100610-73586223
4	225	0.17	20111222-78711342
5	210	0.14	20111103-78038101
6	202	0.11	20110929-77632730
7	306	0.06	20120802-80362911
8	268	0.04	20120501-75971719
9	132	0.04	20100930-74621952
10	211	0.03	20111103-78041250

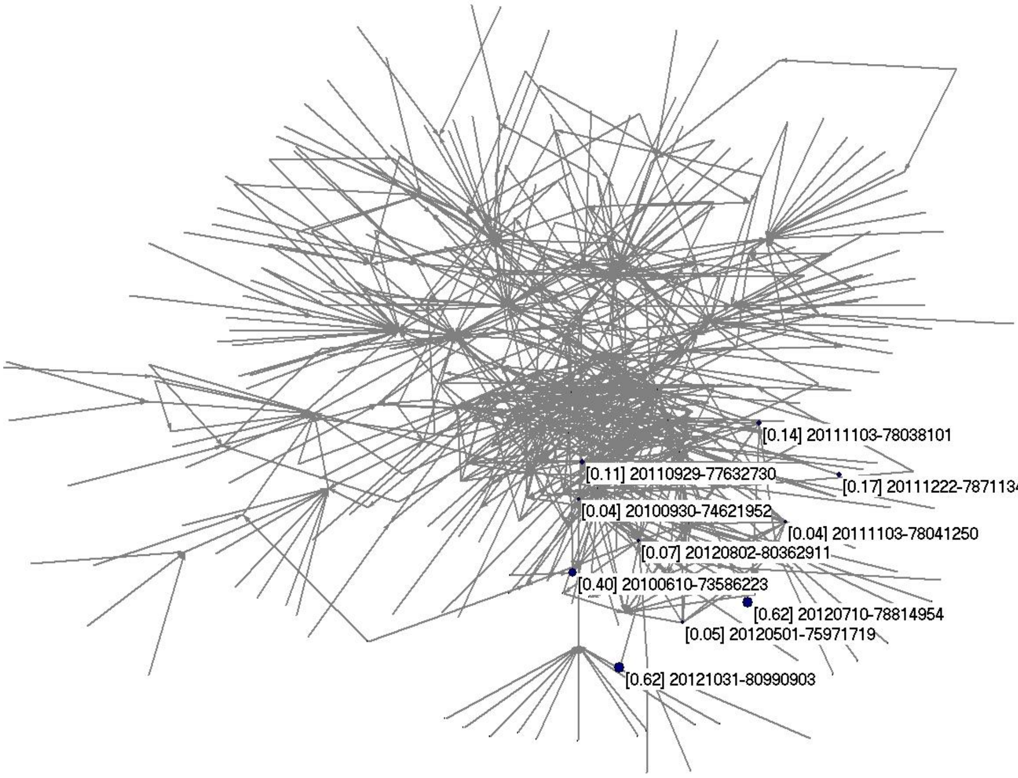

Figure 5.5.NP45. The hub patents of NP45

<u>*SPC (Figure 5.6.NP45, Table 5.12.NP45)*</u> – The SPC algorithm provides a technological trajectory comprising 27 patents, from P45 to the most recent patent vertex 348, owned by the American Solarbridge Technologies with the title 'Modular system for unattended energy generation and storage'. Note that one patent represents a focal point, as shown in Figure 5.6.NP45. This is the American patent (vertex 72), owned by a private inventor with the title 'Photovoltaic Roofing Elements, Laminates, Systems and Kits'.

Table 5.12.NP45. Vertices on main path SPC [flow] of NP45

Rank	Vertex	Value	Id (Label)
1	1	1	20000510-2133382
2	2	1	20040219-15789815
3	3	1	20040708-15789814
4	10	1	20060829-67365978
5	9	1	20060720-07097292
6	85	1	20091215-70535989
7	159	1	20110201-73778022

8	78	1	20091117-71146995
9	131	1	20100902-74387668
10	265	1	20120424-79327262
11	280	1	20120524-79706489
12	268	1	20120501-75971719
13	328	1	20121113-78039768
14	72	1	20091001-71484833
15	210	1	20111103-78038101
16	155	1	20110106-75606264
17	171	1	20110426-73390846
18	125	1	20100715-73623485
19	281	1	20120529-77502789
20	335	1	20121206-79541918
21	307	1	20120807-74317070
22	246	1	20120301-79199318
23	223	1	20111215-78313614
24	271	1	20120503-77906009
25	276	1	20120517-79673857
26	241	1	20120214-78123950
27	348	1	20130108-77275749

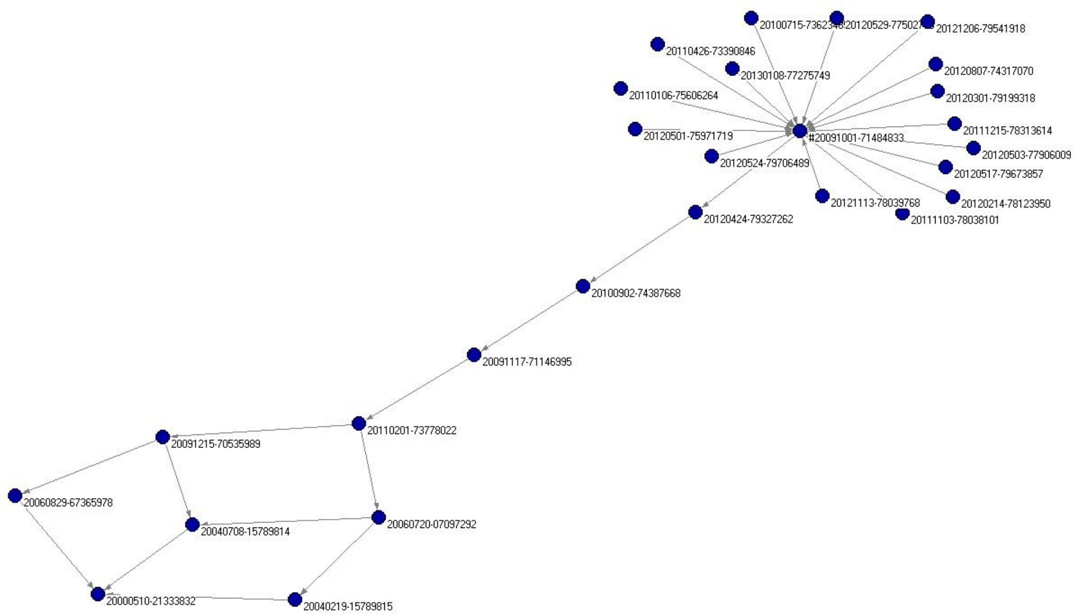

Figure 5.6.NP45. SPC of NP45

5.4. OWA results

This section presents the results of the OWA operator weights for the 53 European patents reported in the Appendix. Table 5.13 shows the 53 patents i = 1,…53 and the number of direct and indirect citations that are considered places j = 1,…,10. From 2000, the first year of publication, there are 10 places. Among the 53 patents published in 2000 within the renewable energy industry, 37 have been cited by others.

In line with the assumption of a power law distribution, we assume a=0.70 give more importance to indirect citations received in the early stages of the patent's life. The OWA model developed by Emrouznejad and Amin (2010) and presented in Chapter 4 is used, hence we have:

	w_1^*	w_2^*	w_3^*	w_4^*	w_5^*	w_6^*	w_7^*	w_8^*	w_9^*	w_{10}^*
α= 0.70	0.2636	0.1472	0.1309	0.1145	0.0981	0.0818	0.0654	0.049	0.0327	0.0163

Table 5.13. OWA score for each patent

Patents	OWA score	Patents	OWA score	Patents	OWA score
P1	1.05	P24	0	P47	0
P2	0	P25	0	P48	0
P3	21.30	P26	0	P49	18.46
P4	3.50	P27	5.80	P50	0
P5	20.71	P28	0	P51	0
P6	2.007	P29	2.43	P52	0.26
P7	0	P30	2.84	P53	0
P8	0	P31	0		
P9	0	P32	2.81		
P10	20.28	P33	0.821		
P11	27.52	P34	0.527		
P12	53.89	P35	3.51		
P13	0	P36	14.42		
P14	1.49	P37	2.13		
P15	0.26	P38	0		
P16	8.63	P39	37.73		

P17	3.69	P40	10.08	
P18	2.02	P41	32.91	
P19	3.79	P42	48.27	
P20	2.93	P43	67.16	
P21	0.67	P44	3.64	
P22	1.72	P45	62.45	
P23	2.92	P46	0.527	

The results (Table 5.13) suggest that the ranking of these 53 European patents is as follow: P43 > P45 > P12 > P42 > P39 > P41 > P11 > P3 > P5 > P10 > P49 > P36 > P40 > P16 > P27 > P19 > P17 > P44 > P35 > P4 > P20 > P23 > P30 > P32 > P29 > P37> P18 > P6 > P22 > P1 > P33 > P21 > P34 > P46 > P15 > P52. The other 16 not cited patents are equal last.

Differently from the OWA scores, the authority weights show a value between 0 and 1. According to the authority weights the ranking is as follow:

P1 = P4 = P14 = P15 = P19 = P29 = P32 = P34 = P35 = P37 = P52 = P46 > P22 > P18 > P33 > P5 > P17 > P6 > P21 > P27. The remaining patents are equal last with a value of zero.

The two rankings differ substantially, as the Wilcoxon test demonstrates. Here we recall again Table 5.6 to show the differences.

Table 5.6. OWA score vs authority weights

Patents	OWA score	Authority weights	Patents	OWA score	Authority weights	Patents	OWA score	Authority weights
P1	1.0545	1	P24	0	0	P47	0	0
P2	0	0	P25	0	0	P48	0	0
P3	21.3036	0.0627	P26	0	0	P49	18.4672	0
P4	3.5018	1	P27	5.8054	0.0022	P50	0	0
P5	20.72	0.1636	P28	0	0	P51	0	0
P6	2.0072	0.0184	P29	2.4327	1	P52	0.2636	1
P7	0	0	P30	2.8454	0	P53	0	0

P8	0	0	P31	0	0			
P9	0	0	P32	2.8145	1			
P10	20.2890	0	P33	0.8218	0.7071			
P11	27.5272	0	P34	0.5272	1			
P12	53.8927	0	P35	3.5199	1			
P13	0	0	P36	14.4254	0			
P14	1.4963	1	P37	2.1399	1			
P15	0.2636	1	P38	0	0			
P16	8.6309	0	P39	37.74	0			
P17	3.6945	0.02	P40	10.0818	0			
P18	2.0236	0.9732	P41	32.9181	0			
P19	3.7945	1	P42	48.2781	0			
P20	2.9309	0	P43	67.1690	0			
P21	0.6745	0.0078	P44	3.6490	0			
P22	1.7290	0.9820	P45	62.4599	0			
P23	2.9290	0	P46	0.5272	1			

5.5. The relation between SNA results and OWA scores

Table 5.6 summarizes the results for each patent. We have reported authority weights only since our patents P1,..., P53 are the starting points in the network and so cannot be hubs.

The SNA identifies core inventions (authority patents) within each network built on the original patent published in 2000. The majority (authorities) are patents published after 2000. SNA provides information on the number of direct citations received by patents published in 2000, but there is no other significant information contained in the corresponding networks. However, the OWA scores provide useful information as discussed early. Note that the interpretation of OWA weights proposed in this section is in line with Yager's (1988) original description of the OWA operator as differing from the classical weighted average; the coefficients are associated with an ordered position rather than a particular attribute. For this reason each OWA score has to be related with the places in which indirect citations appear.

Below the initial patents are presented according to their OWA scores:

1. P43 is the first patent within the OWA ranking with a score of 67.16. Given our assumption about the citations distribution, it is reasonable to attribute more importance to indirect citations received in the early stages. Therefore, the OWA score reflects the importance of P43 within its network. While it is not an authority patents in NP43. NP43 is comprised of more than 100 nodes and the authorities are the patents published 10 years after P43. Having identified the core inventions in NP43 we can categorize them as 'descendents' of the original P43 published in 2000;
2. The second patent according to the OWA ranking, is for P45, with a score of 62.45. The OWA score informs about the indirect citations received by P45 in the early stages. Conversely, the authority weight accounts for direct citations only. P45 is not an authority. NP45 is comprised of more than 100 nodes and authority patents were published 10 years after P45;
3. P12 is the third patent according to the OWA ranking, with a score of 53.89, which reflects the citations distribution of NP12, which includes hundreds of nodes. P12 is not an authority in NP12;

4. P42 is the fourth ranked patent, with a score of 48.27. The OWA score reflects the importance of P42 within its network for diffusing knowledge considering its indirect citations rather than just the direct ones, culminating 10 years later in the highest number of authority patents. NP42 comprises more than 100 nodes and the authorities are patents published in 2010;
5. P39 has a OWA score of 37.73; it is not an authority patent, but received indirect citations in its early stages, for this reason the orness level chosen (0.70) reflects the role of P39 in its network considering indirect ties;
6. P41 has a score of 32.91 and it is not an authority in its network. However, the majority of forward citations are in the early stages of P41's life, thus, it is reasonable to accept the score as reflecting its real value;
7. P11 scores 27.52, but in this case the citations were not in the early stages of its life. To evaluate its role it is better to adopt an orness level, which attributes more importance to later citations, for example a=0.90;
8. P3 has a score of 21.30, and its citations appear in the early stages of its life, so the score reflects its value in spreading knowledge within its network, which is characterized by authorities published between 2007 and 2011. P3 has an authority weight of 0.06, which ranks it as the 5th authority patent in its network;
9. P5 has a score of 20.71, and its citations do not appear in the early stages. Simiarly to P11, in this case an orness level which attributes more importance to later citations, for example ($\alpha = 0.90$), would be more appropriate;
10. P10 scores 20.28 and its citations appear in the early stages, so the score reflects its value for spreading knowledge within its network. P10 is not an authority patent in its network;

11. P49 has a score of 18.46, which is in line with its citations distribution. It is not an authority in its network;
12. P36 scores 14.42 and its citations follow more a normal distribution, thus, higher orness level (e.g. 0.90) could be more applicable;
13. P40 scores 10.08 and its citations are in the early stages, so the score reflects its value. It is not an authority in its network;
14. P16 has a score of 8.63, which reflects its value since its citations are in the early stages; it is not an authority in its network;
15. P27 has a score of 5.80; its citations follow a distribution similar to a normal curve, thus, higher orness level (e.g. 0.90) could be more applicable;
16. P19 has a score of 3.79, which reflects its value, given its citations distribution;
17. P17 scores 3.69 and its citations distribution does not follow a power law;
18. P44 has a score of 3.64 and its citations follow more a normal distribution, thus, orness level (0.90) is more appropriate; it is not an authority in its network;
19. P35 scores 3.51, it has only two places of citations and these do not appear in the first stage, but in the second; it is an authority in its network;
20. P4 has a score of 3.50, which reflects its value, given its citations distribution;
21. P20 scores 2.93, it has only two places of citations and these do not appear in the first stage, but in the second; it is not an authority in its network;
22. P23, P30, P32, P29, P37, P18 and P6 have a score between 2.92 and 2. Their networks are small with no more than 3 places to rank.
23. The remaining patents, P22, P14, P1, P34, P46, P15 and P52 have a score between 1.729 and 0.263, with very small differences, which reflects their value given the distribution of their citations.

24. The others, P2, P7, P8, P9, P13, P24, P25, P26, P28, P31, P38, P47, P48, P50, P51, P53 score 0 since they did not receive any forward citations.

The OWA scores allow the patents to be ranked according to their indirect citations, allowing inferences about which previous patents were effective for generating future innovations. To summarize, the top patents according to the OWA ranking (P43, P45, P12, P42, P39, P41, P11, P3, P5, P10, P49) are those with the most influence on subsequent technological developments in their particular networks. The technological developments have been identified as the authorities within each NP.

It can be concluded that P43, P45, P12, P42, P39, P41, P11, P3, P5, P10, P49 are the 10 most effective patents for spreading the knowledge embedded in them, generating complex networks in the subsequent 13 years, and reaching maturity in year 10 with the publication of another patent.

5.6. Conclusions

In this chapter we have shown two different ways of ranking the original patents published in 2000 within the renewable energy industry, considering for the first time the indirect citations received by each one and the places in which these citations appear. The focus has been on the authority weights obtained by each original patents. As it has been shown in Chapter 3, hubs and authorities are calculated considering only direct ties. We compared the authorities weight with the OWA score, calculated considering indirect citations. Furthermore, the indirect citations have been considered as related to the places (1,…,10) in which they appeared. In doing so, we assumed that patent citation distributions follow a power law, as described by studies presented in Chapter 2.

Following this analysis and interpretation of the OWA weights a second application is proposed in Chapter 6. The network object of the second study differs from those analysed in this chapter since it is a network composed of people rather than patents and because the knowledge flows are characterized by tacit rather than explicit knowledge.

Chapter 6. A company supply chain knowledge network: A case study

6.1. Introduction

This chapter studies the knowledge flows in the network context of a supply chain in order to analyse the knowledge transfer and knowledge creation processes among internal and external ties. First, SNA is applied to map the internal structure of knowledge transfer within a company. In contrast to what was described in Chapter 5, this context is characterized by tacit knowledge embodied in individuals and knowledge relations. Given the characteristics of this type of knowledge, this requires qualitative data, which are discussed together with the SNA and OWA application. Second, a qualitative in-depth analysis of the company has been used to depict the network along the company supply chain. Data collection is described in the next section.

6.2 Data Collection and Analysis

The approach adopted in this chapter is based on data gathered through an in-depth case study, combined with insights from SNA and OWA. These three sources are appropriate for analysing knowledge transfer and knowledge creation processes among the internal and external ties and the analysis of the indirect ties discussed earlier in this thesis. Case selection was based on a theoretical sampling approach (Eisenhardt and Graebner, 2007). The automotive industry was chosen on the basis of its being one of the most complex sectors in relation to the technologies and players involved in the production process (Maxton, 2004), and a manufacturer of rubber automotive components was selected as the case company, which we will call ALPHA.

After case company selection, a meeting was held with senior management and the first round of six interviews was conducted to collect information on the company; we also collected company publications and documentation on the company's history. Thus, our data sources were company documentation, direct observations and interviews. This allowed triangulation of data from different sources (Eisenhardt, 1989; Choi and Hong, 2002) and enabled identification of a particular group of interest within the company, the Quality Assurance Group.

There are two main approaches to studying a network or linkage within a company: egocentric, and bounded (Cross and Parker, 2004). An egocentric approach involves the collection of data from one individual who identifies others who are important. The purpose is to identify the group team leader or the most central node in an informal network. According to Cross and Parker (2004), the main advantage of egocentric network analysis is that it can reveal all the focal individual's important relationships. A bounded network approach involves identification of a network of interest, perhaps a particular department such as R&D or Quality Assurance, which was the group chosen for the analysis. In our case, the focus of the company on the management of quality leads to the choice of the Quality Assurance Group. The researcher administered a questionnaire to every member of the group to obtain details of their relationships with other group members. The choice of a bounded approach was based on the characteristics of ALPHA and its Quality Assurance Group, and the introduction by ALPHA of total quality management (TQM) and Six Sigma, which had affected the company's operational performance.

The most frequent method used to collect relational data is questionnaire; there are two main questionnaire models that can be drawn on to design a SNA survey:

a) a recognition model, which provides respondents with a list of names of organizational members and relies on the idea that respondents may forget even important people. Providing a list avoids this possibility. However, when studying an entire supply chain or a complex organization the list can be too long to be of practical use. A major critique of this kind of questionnaire is that provision of a list may influence people to select some names and not others;

b) a free recall questionnaire which allows the respondent to identify those people considered to be important. Thus, the respondent identifies the actors. A free recall questionnaire was used to collect data from ALPHA. It was chosen because the recognition model would have been very long, considering all employees within the company (300), thus more difficult to manage for the respondents.

As in Chapter 5, we start from the assumption that knowledge percolates from one node to another in a network, and that indirect ties also allow knowledge transfer. Our hypothesis in relation to the research questions is that if crucial knowledge is developed through ties, then the nodes with highest authority weights (core knowledge nodes) will have more information and knowledge and, to the extent that the information and knowledge have an impact on areas such as quality, will show better operational performance.

The SNA questionnaire, presented at the end of this paragraph, was administered to the Quality Assurance Group which comprises 8 individuals and to the director of the R&D Department, in order to map the internal knowledge-based ties across the group These 9 individuals nominated 2 other employees from different departments, the CEO and the Director of the Extrusion and Finishing Department . They also were surveyed, thus a total of 11 individuals responded. Table 6.1 shows the role of each respondent within the company. The questionnaire was developed following Cross and Parker's (2004) work on conducting and interpreting SNA. The questionnaire was followed-up by email exchanges with the respondents where further clarification was needed. We asked respondents to ask the questions reported in the questionnaire to identify the individuals they talk with to solve daily problem activities, to take an important decision and those considered the most important for the innovative process of the company. According to the SNA prescriptions, the data have been used to create an adjacency matrix in which the value 1 represents the tie between individuals and 0 represents the absence of ties. These represent the relational data needed to conduct a SNA application. Thus, the data collected via the survey were analysed using Pajek software, and allowed us to map the organization's internal knowledge-based ties and identify the most central nodes in the network, using centrality measures and authorities weights. We then applied OWA to rank the indirect relations that emerged in the network. Results were shared with the individuals emerging as the most important according to the SNA and OWA results and with the organization's top management. The interviews conducted with all these people led to a better understanding of the role of each node in cultivating, nurturing, managing and driving the management of knowledge-based ties. The in-depth interviews confirmed the crucial role of the individuals ranked using the OWA, and identified the organization's external knowledge-based ties. Finally, learning outputs were identified.

Note that the map of the internal knowledge-based ties has been carried out by means of the SNA questionnaire, while the map of the external knowledge-based ties has been carried out through the qualitative analysis and in-depth interviews.

SNA questionnaire

Identify internal collaborators

1.1 Who do you most often turn to in your daily work activities (in thinking through a new or challenging scientific or technical problem) within your company? Please indicate up to 5 people.

Name, Surname	Company unit

1.2 Please indicate the people you consider to be the most important for the innovative product development process of the firm. Please indicate up to 5 people.

Name, Surname	Company unit

1.3 Please indicate whom you turn to for input prior to making an important decision. Please indicate up ti 5 people.

Name, Surname	Company unit

Interview guide used for in-depth ex post interviews

- Please tell us about your position in the company, how long have you been working within the company, indicate the number of years within the company and in your current positions;
- Please tell us the most crucial innovations undertaken by the company;
- Please tell us about your most important competitors;
- Please tell us about your most important business partners;
- Please tell us about the relation between ALPHA and the buyer company;
- Please tell us about the motivation behind the quality management decisions undertaken over the last 10 years;
- Would you show us your most recent research projects?
- What is your role in carrying out these research projects?
- What do you think are the strength points of these research projects?
- What are the company's most important achievements in term of operational performance improvement, in your opinion?

Table 6.1. Description of each respondent within the company

Name	Role	Department	Number of years in the company
A	Quality Manager and Master Black Belt	Quality Assurance Group	10
B	Director of the Quality Assurance Group and Master Black Belt	Quality Assurance Group	10
C	Director of R&D Department	R&D Department	8
D	Quality controller	Quality Assurance Group	5
E	Quality Manager	Quality Assurance Group	6
F	Senior quality controller	Quality Assurance Group	8
G	Employee	Quality Assurance Group	7
H	Employee	Quality Assurance Group	5
I	Employee	Quality Assurance Group	5
L	Director of Extrusion and Finishing Department and Master Black Belt	Extrusion and Finishing Department	10
M	CEO	Top Management	16

6.2.1. The manufacturing company ALPHA

The object of our analysis is the manufacturing company ALPHA, which is a supplier of rubber car components to a major Italian auto manufacturer. The company is located in Italy, and was founded in 1972. Over the past 40 years, the company has taken several strategic decisions. In 1982, its fundamental product sector became the profile for automotive and industrial application; in 1985, it launched its R&D activity. Between 1990 and 1992, its production was exported to foreign markets. During the period of our analysis, it had 300 employees. The company adopted Six Sigma in 1999.

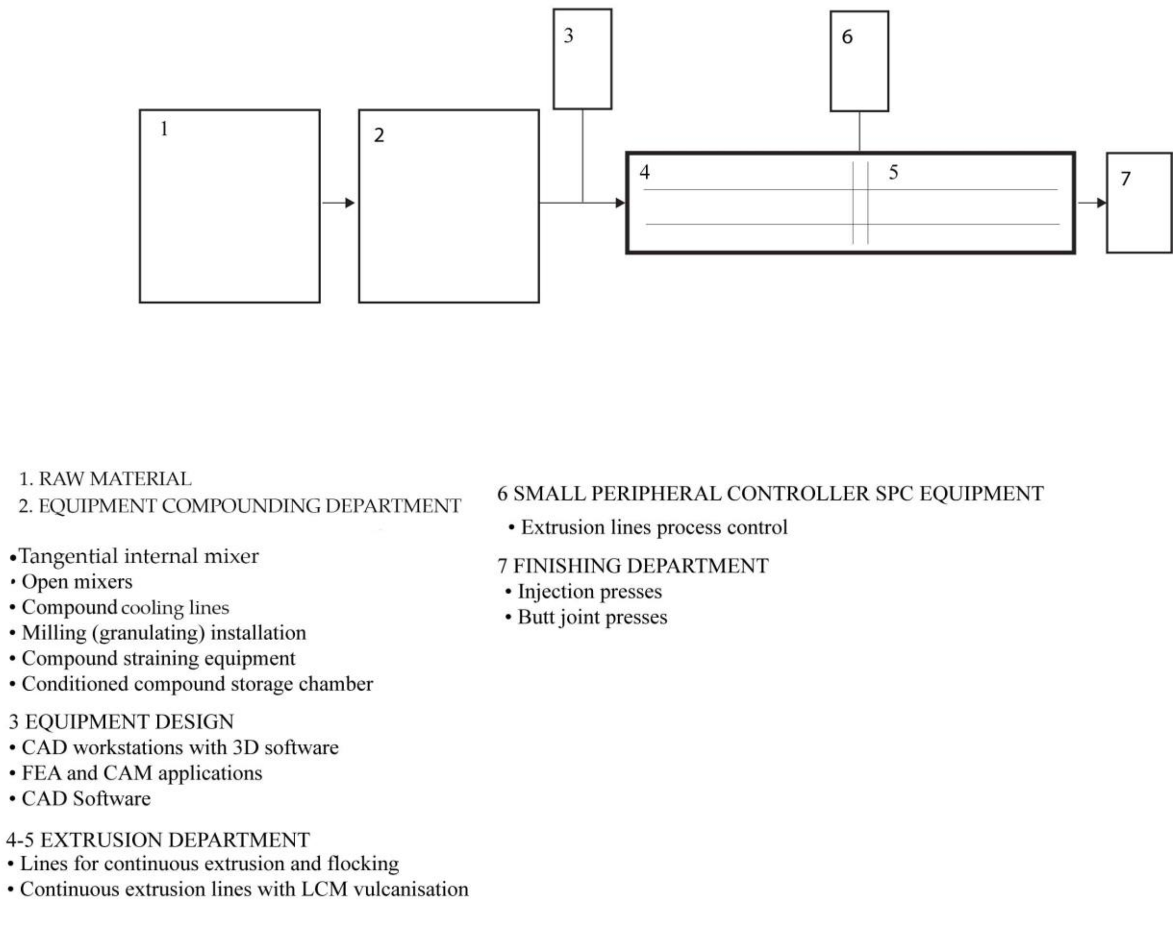

Figure 6.1. Departmental plan of ALPHA

The company has to manage three major complex quality problems:

- the specificity of the material (rubber), which involves several technical problems. High temperatures are required, which make the material fragile subject to becoming deformed. The makeup of the rubber to obtain the required viscosity is complicated. The shape of the final component is strongly affected by the high temperatures in the extrusion line (Figure 6.1, points 4-5);
- size of final component – for the above described reasons, achieving accurately sized output is difficult. The company produces semi-finished products to be assembled into the final product by the buyer - the automobile manufacturer. To adhere to the measures required by the buyer, the margin of error in the size of the final component is very small;
- process - the production process needs to be standardized in order to reduce errors in the extrusion line.

6.3. SNA results

We have hypothesized that the core knowledge nodes (highest authority weights) in the knowledge-based ties are the knowledge accumulating nodes. The knowledge accumulating nodes are the most knowledgeable people in the organization, key employees who determine the development of organization-specific knowledge, who embody important knowledge, and who contribute to the development of new knowledge. If the goal is to create new knowledge and to exchange existing knowledge, then we need to focus on the most knowledgeable individuals or groups in the company.

Figure 6.2 depicts the internal knowledge transfer structure among the members of the Quality Assurance Group and the members of the other groups they identified. For reasons of anonymity all nodes are referred to by randomly chosen letters of the alphabet. A, B, D, E, F, G, H, and I are members of the Quality Assurance Group. The arrows on the ties between the nodes show the direction of their nomination. Reciprocal nominations are indicated by a two-way arrow.

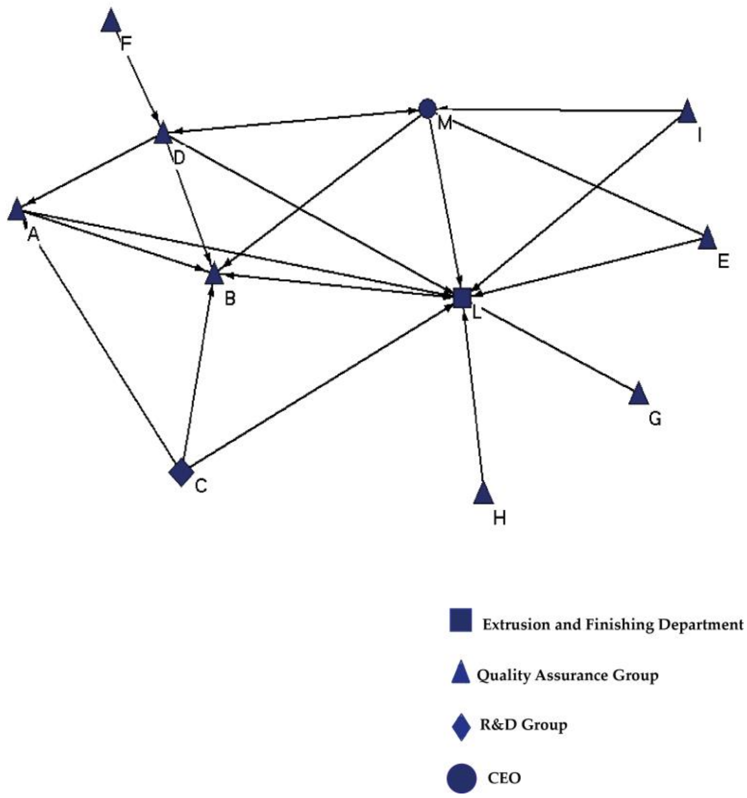

Figure 6.2. Internal knowledge-based ties that constitute the structure for knowledge transfer

The map of the internal knowledge-based ties is depicted in Figure 6.2, and the centrality measures, including the authority and hub weights, of the nodes are depicted in Figures 6.3 to 6.7, and are reported in Tables 6.2 to 6.5. As already stated, following Borgatti and Li (2009) we expect the nodes with the highest value for the centrality measures, including the authority weights, are considered the most knowledgeable individuals. Figure 6.2 shows that the knowledge transfer structure relies on collaboration between the Quality

Assurance Group (nodes A, B, D, E, F, G, H, and I), R&D (node C), the Extrusions and Finishing Department (node L), and the CEO (node M), which are connected by the corresponding knowledge-based ties. This first visual output maps the informal relations in the company.

In-degree centrality measure, and authority weights (Table 6.2 and 6.4, Figure 6.3 and 6.6) confirm the following rankings:

1. Node L is first;
2. Node B is second;
3. Node M is third;
4. Node A is the fourth;
5. Node D is the fifth.

Five nodes show high values and are regarded as the most central. There are a number of important observations. Node L has the biggest shape with a corresponding value of in-degree centrality equal to 9, and highest authority weight of 0.78. This means that it was chosen by the highest number of other members, who consider it the most influential for the company's quality improvements. This individual (node) is the person that others consult most often about problems arising in their day to day work activity. The problems object of the relation between the nodes mapped relate to the management of quality issues. Node B scores second highest (in-degree=5, authority weight=0.48), followed by Node M (in-degree=3, authority weight=0.30), Node A (in-degree=2, authority weight=0.25), and Node D (in-degree=2, authority weight=0.11). These individuals/nodes can be considered the most knowledgeable. They absorb and embody knowledge and competences that allow them to generate new knowledge applicable to the company's main quality problems. The knowledge transfer, accumulation and creation processes analysed in this case study company deal mainly with the improvement of the quality standard as requested by the buyer company and by the final customer. For this reason the decision made by these individuals are about the TQM practices adopted. As mentioned, the company invested in a long training period to learn about the Six Sigma methodology and the lean manufacturing culture. These individuals have the greatest influence over the organization's internal and external knowledge-based ties.

Table 6.5 displays values of hub weights. Given the different nature of this network, we do not consider hubs as the development of the authorities, but, following the original conceptualization, we assume authoritative individuals linked to other good individuals (hubs) in terms of knowledge transfer. In other words, we look at the reinforcing relationship between hub and authorities. Nodes D, M and A are both very good authorities and very good hubs (top four hub weights, values between 0.49 and 0.34), followed by Node C as the second best hub (hub weight=0.41). This ranking reflects the out-degree centrality values (Table 6.2) and shows the strong internal connectivity of these three nodes. Nodes E and I obtained the same value of 0.29, they are both linked to two good authorities Node L and Node M. Nodes H, G and B are equally ranked, with a value of 0.21. They are linked to L only. Finally Node L (the most knowledgeable individual) obtained a value of 0.13, he is linked to a good authority, which is Node B, and Node F, linked to Node D only, obtained a value of 0.03.

Table 6.2. In-degree and out-degree centrality values

Rank	In-degree centrality			Out-degree centrality		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	10	9	Node L	4	4	Node D
2	2	5	Node B	11	3	Node M
3	11	3	Node M	3	3	Node C
4	1	2	Node A	1	2	Node A

5	4	2	Node D	5	2	Node E
6	7	0	Node G	9	2	Node I
7	6	0	Node F	2	1	Node B
8	5	0	Node E	8	1	Node H
9	9	0	Node I	7	1	Node G
10	3	0	Node C	10	1	Node L
11	8	0	Node H	6	1	Node F

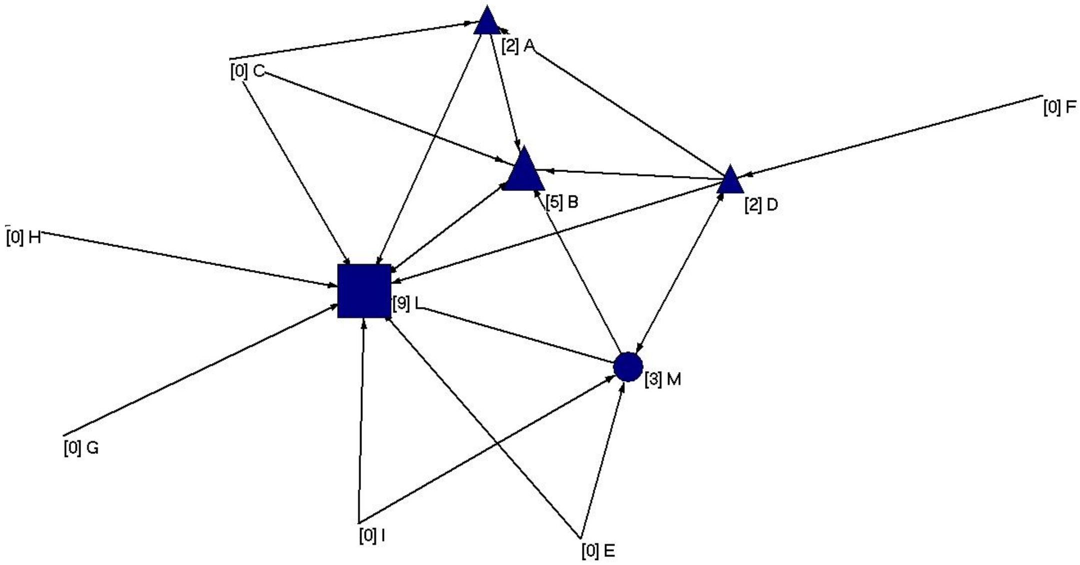

Figure 6.3. In-degree centrality measure and the knowledge accumulating nodes

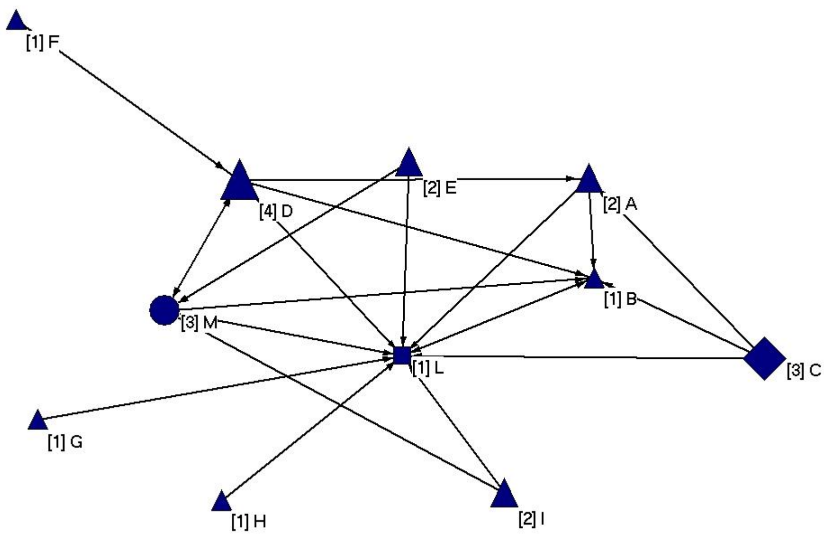

Figure 6.4. Out-degree centrality measure

Table 6.3. Closeness centrality measure

Rank	Vertex	Value	Id (Label)
1	10	0.91	Node L
2	2	0.67	Node B
3	11	0.67	Node M
4	4	0.67	Node D
5	1	0.63	Node A
6	3	0.56	Node C
7	9	0.53	Node I
8	5	0.53	Node E
9	7	0.50	Node G
10	8	0.50	Node H
11	6	0.42	Node F

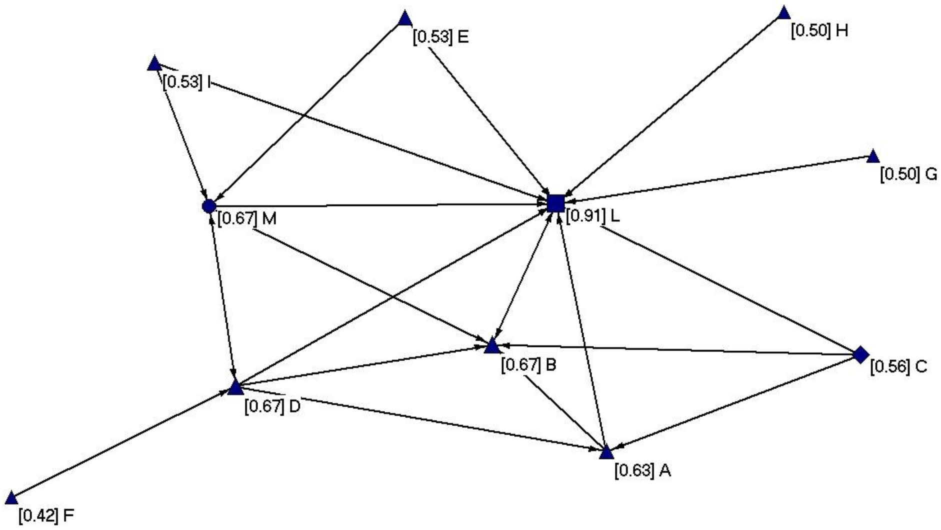

Figure 6.5. Closeness centrality measure

Table 6.4. The authority weights

Rank	Vertex	Value	Id (Label)
1	10	0.78	Node L
2	2	0.48	Node B
3	11	0.29	Node M
4	1	0.24	Node A
5	4	0.11	Node D
6	7	0.00	Node G
7	6	0.00	Node F
8	5	0.00	Node E
9	9	0.00	Node I
10	3	0.00	Node C
11	8	0.00	Node H

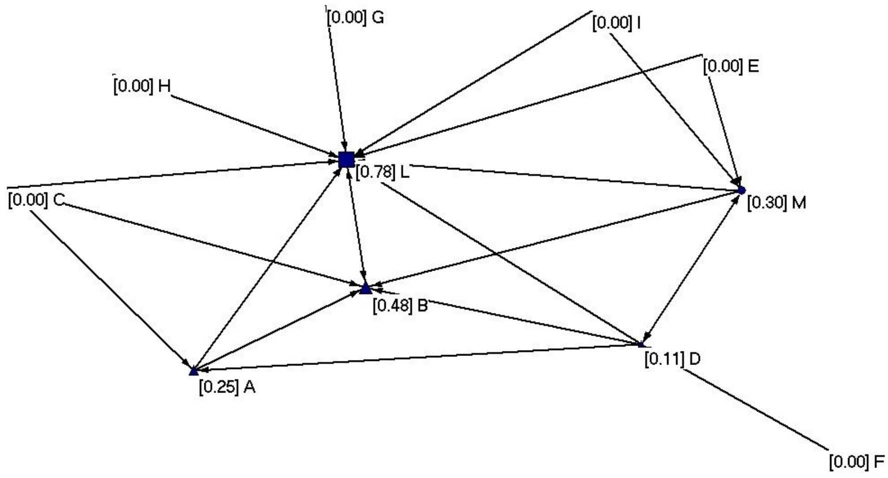

Figure 6.6. Authorities of the network

Table 6.5. The hub weights

Rank	Vertex	Value	Id (Label)
1	4	0.49	NodeD
2	3	0.41	NodeC
3	11	0.37	NodeM
4	1	0.34	NodeA
5	5	0.29	NodeE
6	9	0.29	NodeI
7	8	0.21	NodeH
8	7	0.21	NodeG
9	2	0.21	NodeB
10	10	0.13	NodeL
11	6	0.03	NodeF

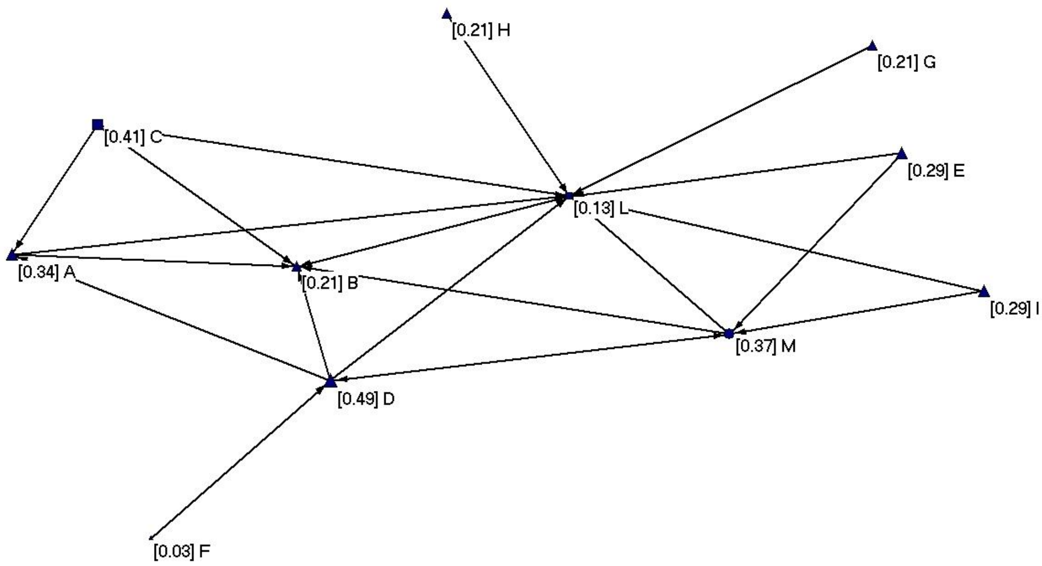

Figure 6.7. Hubs of the network

6.4. OWA results

This section presents the results of the OWA operator weights for the 11 nodes (employees). Table 6.6 shows the 11 nodes, $i = A,\ldots,M$ and the number of direct and indirect ties that are considered places *j*=1,2,3. The three places, refers to the three levels of ties; the first refers to direct ties, the second and third to indirect ties. We assume α=0.70, for consistency with Chapter 5 and in line with the consideration that in a network, such as in this study, which is characterized by high levels of tacit knowledge, knowledge transfer is not confined strictly to the boundaries of a direct relation but it cannot be transmitted through several indirect ties.

Table 6.6. The number of direct and indirect ties

Node	1st Place	2nd Place	3rd Place
Node A	2	2	1
Node B	5	5	2
Node C	0	0	0
Node D	2	2	0
Node E	0	0	0
Node F	0	0	0
Node G	0	0	0
Node H	0	0	0
Node I	0	0	0
Node L	9	1	0
Node M	3	1	0

The OWA model developed by Emrouznejad and Amin (2010) and presented in Chapter 4 is used, hence we have:

	w_1^*	w_2^*	w_3^*
$\boldsymbol{\alpha}$= 0.70	0.55	0.3	0.15

Weights show that orness =0.70 gives a higher importance to the first place ($w_1 = 0.55$). The results (Table 6.7) suggest that the ranking is as follow:

Node L> Node B > Node M> Node A> Node D.

Table 6.7. The OWA score

Node	OWA scoreEA70
Node A	1.85
Node B	4.55
Node C	0
Node D	1.7
Node E	0
Node F	0
Node G	0
Node H	0
Node I	0
Node L	5.25
Node M	1.95

6.5. The relation between SNA and OWA scores

Table 6.8 summarizes the results for each node. As in Chapter 5, we compare OWA with authority weights. Interestingly and as expected they do not differ. This might be because of the presence of few direct and indirect ties (only three places). Although the ranking is similar the OWA weights and the corresponding scores rank Node B very much closer to L and much further away from the others than the authority weights. Furthermore if we consider the closeness centrality measure (Table 6.3) it ranks Node B equal to Node M and D, so it does not discriminate among them. This also confirms that OWA is overall a better measure for network analysis, in the larger network OWA assigns more weights to indirect citations and so it is a more realistic ranking method as compared to SNA,

Table 6.8. OWA score vs authority weights

Node	**OWA score**	**Authority weights**
Node A	1.85	0.24
Node B	4.55	0.48
Node C	0	0
Node D	1.7	0.11
Node E	0	0
Node F	0	0
Node G	0	0
Node H	0	0
Node I	0	0
Node L	5.25	0.78
Node M	1.95	0.29

The role of each member is described as follows, and summarized in Table 6.9.

- According to the SNA and OWA results Node L is the most influential node, with the greatest access to information and knowledge. OWA confirms his 1st position in the ranking. He was not a member of the Quality Assurance Group during the period of our analysis, but was important to the knowledge transfer process within the organization and with the external environment. At the time of writing, he was Director of the Extrusion and Finishing Department. Node L is identified as the most important person in relation to the quality improvement processes undertaken by the organization over the years, and the most useful for problem solving. He is regarded as a knowledge broker. He introduced a benchmarking system against competitors and was responsible, together with Node B, for introducing TQM programme in ALPHA. Nodes L and B are involved in reciprocal ties. Node L also acts as a bridge between ALPHA and its competitors, suppliers and subcontractors. These relationships are discussed in more detail later;

- Node B is the Director of the Quality Assurance Group. Together with Node L, he was responsible for introduction and implementation of the TQM programme in the company. He acts as a bridge between ALPHA and its suppliers, in collaboration with Node L;
- Node A is one of the group's Quality Managers and was the first to achieve the Master Black Belt,[8] the highest qualification, in the Six Sigma scheme. This is discussed further in succeeding sections;
- Node M is the CEO. If top management agrees with and supports the strategies proposed by other members of the company, their implementation is more likely to be successful and to have an impact on operational performance. Node M acts as a bridge between ALPHA and a university research centre where he has personal contacts. He has a reciprocal tie with Node D;
- Node D acts as a gatekeeper between ALPHA and an important external partner, the university research centre, where he worked on a software tool to monitor the extrusion line process. At the time of the fieldwork, D had been recently recruited from the university research centre. He collaborated with ALPHA on the development of the software and, subsequently, took up full time employment in ALPHA;
- Node C (Director of R&D Department) is not a member of the Quality Assurance Group. It should be noted that Node C shows an out-degree value of 3 but zero

[8] The Six Sigma approach involves different levels of expertise: Yellow Belt is the lowest level and the progression goes through Green Belt to Black Belt and Master Black Belt – the highest level of Six Sigma expertise.

in-degree value. This indicates that others have not nominated him, but he nominates individuals (good authorities) important for the knowledge transfer and creation processes. It also indicates that he is a gatekeeper for his department which relies heavily on the input received from the Quality Assurance Group and the Extrusion and Finishing Department.

Table 6.9. Description of ALPHA's internal members and their performance

Name	Role	Department	Number of years in the company	Individual performance
A	Quality Manager and Master Black Belt	Quality Assurance Group	10	One of the most knowledgeable individuals
B	Director of the Quality Assurance Group and Master Black Belt	Quality Assurance Group	10	Bridge with suppliers and subcontractors
C	Director of R&D Department	R&D Department	8	Bridge with the Quality Assurance Group and the Extrusion and Finishing Department
D	Quality controller	Quality Assurance Group	5	Gatekeeper between ALPHA and The Research Centre
E	Quality Manager	Quality Assurance Group	6	
F	Senior quality controller	Quality Assurance Group	8	
G	Employee	Quality Assurance Group	7	
H	Employee	Quality Assurance Group	5	
I	Employee	Quality Assurance Group	5	
L	Director of Extrusion and Finishing Department and Master Black Belt	Extrusion and Finishing Department	10	Broker of access to different sources of knowledge and bridge with suppliers and subcontractors

M	CEO	Top Management	16	Bridge between ALPHA and the university research centre

6.6. External knowledge-based ties: A qualitative investigation

Drawing on the information derived from the in-depth interviews with the five most central nodes identified, A, B, D, L and M, we can explore the external knowledge-based ties. These were identified by the most knowledgeable individuals who are the *drivers* of those ties. Figure 6.8 depicts the external knowledge-based ties of ALPHA. Table 6.10 presents the related roles and main learning outcomes of each of these ties, and the implications for operational performance.

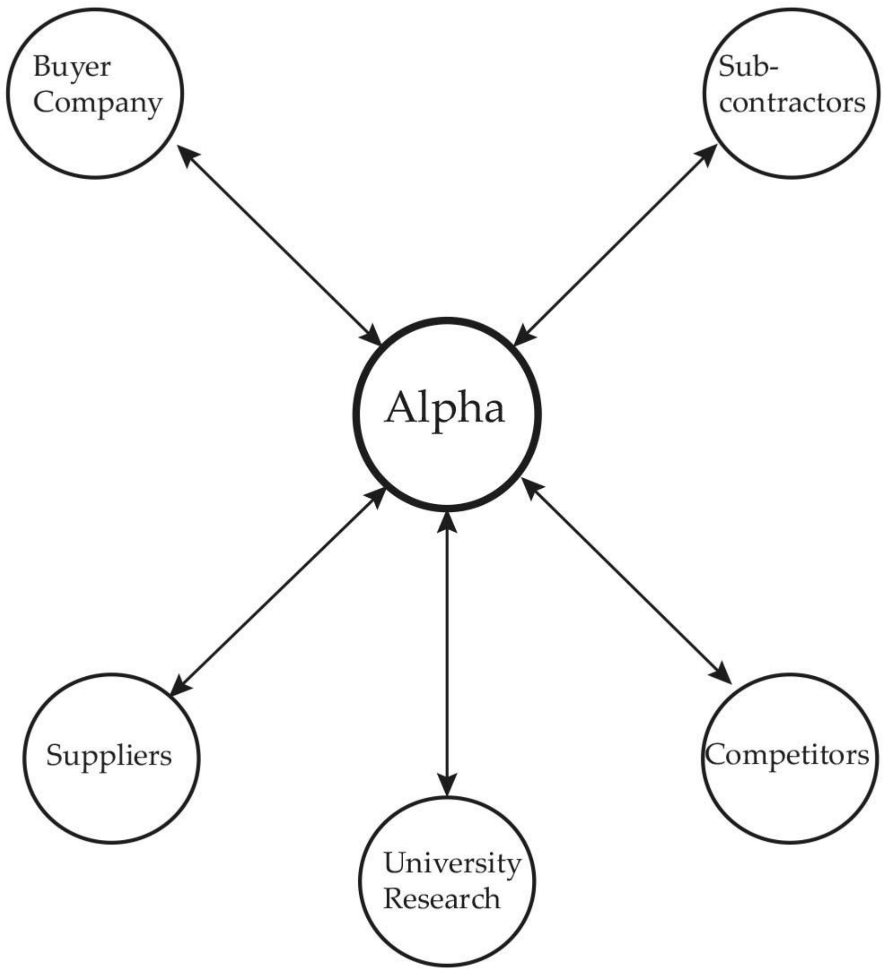

Figure 6.8. External knowledge-based ties

Table 6.10. Learning outcomes and impacts of external knowledge-based ties

Partner	Knowledge-based ties	Length of knowledge-based tie	Output/Learning outcome	Operational Performance
Buyer company	Knowledge sharing about improvement of product quality	On-going relationship	Acquisition of the awareness about improvement of product quality in the market scenario	Strict control of measures and parameters to produce highly precise products with respect to the buyer's specifications
Competitors	Knowledge sharing about TQM practices	2 years	Acquisition of knowledge about Six Sigma implementation	Improved process control and product quality; Reduced wastes
University research centre	Knowledge exchange for the software development to monitor the entire production process	3 years	Development of the algorithm and the patented software tool	Increased new product development performance; Increased flexibility and customization; Reduced costs
Suppliers	Knowledge sharing about the best TQM practices	On-going relationship	The suppliers introducing the same TQM practices in their daily activities became 'talented suppliers'	Reduced inventory level and increased speed in answering requests; Increased level of customer satisfaction
Subcontractors	Knowledge sharing about the best TQM practices	On-going relationship	They grew up together with Alpha from micro enterprises to small enterprises	Reduced inventory level and increased speed in answering requests; Increased level of customer satisfaction

ALPHA – buyer company

The traditional buyer-supplier relationship is affected by the buyer's changing demands. The buyer company has undergone several radical changes and demands high quality from ALPHA. For example, in 1994, the parts per million (PPM) of error accepted by the buyer was 5,700; in 2008 the margin was 258. This required ALPHA to radically improve the quality of its output.

The knowledge-based link between the buyer and supplier organizations allowed the sharing of information and knowledge about the level of quality expected by final customers. The information was transferred in a series of meetings between the buyer's managers and representatives of ALPHA's Quality Assurance Group. After a long learning period, ALPHA achieved stricter control of measures and parameters.

ALPHA - competitors

As a part of the continuous effort to increase quality to meet buyer's requirements, ALPHA engaged in benchmarking against some of its competitors to understand how other companies in the same industry managed the quality of their output.

The linkage established with one of the major European automotive manufacturers working in the luxury market segment was aimed at enabling benchmarking activities. It allowed ALPHA to learn more about how these companies achieved the required quality. It resulted in greater awareness of the importance of *lean* and how to achieve it. The Quality Assurance Group began working towards ISO9000 qualification, common in the automotive sector, which involved a series of wider benchmarking activities. Its representatives visited factories in Europe to observe their methods, and several employees were involved on exchanges to other organizations. As a result, ALPHA decided to invest in training programmes on lean manufacturing and related TQM practices.

ALPHA chose to adopt Six Sigma in order to increase customer satisfaction, reduce the costs related to poor quality output, train employees, use inter-functional team-working, and implement a continuous improvement methodology aimed at achieving world-class quality. ALPHA needed Six Sigma certification, and the CEO agreed to employees involved in the benchmarking being trained up to Master Black Belt level. The Six Sigma methodology is designed to reduce waste and costs, and to improve the overall quality of processes and products. An interviewee told us that: 'It became suddenly evident that it was not reasonable to disseminate the culture of Six Sigma at all levels of the company. It is very complicated and not intuitive'.

The Six Sigma approach requires advanced statistical capabilities and a particular way of thinking about the production process. The Quality Assurance manager told us that: 'As we learnt during the course, with Six Sigma the process is not more under control but it is in control (…). The main result of a Six Sigma implementation is not more output; it refers to the entire process. It changes our way of thinking the production process, because it includes the entire process not just the final product'.

At the same time, one of the principles of a lean strategy is that the whole organization should be involved in the improvement process. This principle was implemented following the initial Six Sigma training, in order to diffuse the culture of continuous quality improvement to all employees. This bottom-up strategy was achieved through application of Kanban and Kaizen, especially in storage and warehousing. Kanban and Kaizen are often seen as central elements of the 'lean manufacturing' system. These two approaches deal with the culture of continuous improvement within the organization. The company achieved significant reductions in inventory levels and production costs.

Two aspects need highlighting:

- Six Sigma was successful in reducing variability in the output of the Equipment and Compounding Department, and monitoring dimensions of the extrusion line. Six Sigma was introduced specifically to reduce the margin for error in the use of raw materials and to control the temperature in the mixing room, to reduce the time needed to switch between operations, and to reduce the number of errors in the extrusion line. A Six Sigma project was implemented in the mixing room, where the main problem was the viscosity of the rubber. To decrease process variability, the acceptable viscosity range was revised. This led to savings amounting to €15,000 as a result of less re-working of compounds. The company achieved a 20.1% reduction in errors along the extrusion line, which, combined with the resulting time savings, reduced production costs by €20,000. A Six Sigma project was also introduced into the Design Activity, but produced no major benefits. Overall, Six Sigma changed the company's problem solving activities;
- Kanban and Kaizen methods were employed to improve the production process, and involve the entire organization (all employees) by suggesting how to improve daily working activities. The main improvements were to reduce inventory levels and warehousing activities. Kanban and Kaizen methods had the biggest effects on the Finishing Department. Note that this emerged from the qualitative analysis conducted within the case company, through the analysis of company's documentation and the interviews conducted. We can conclude that,

in a case study research, a qualitative investigation complements and strengthens the quantitative insights from the SNA and OWA results.

To summarize, the main purpose of the knowledge-based linkage with competitors was to share knowledge about the lean manufacturing approach and TQM practices. The main results were knowledge about the crucial role of TQM practices for providing superior value to the final customer and reducing costs, and accumulation of expertise in the application of different TQM practices, by employees in different departments.

ALPHA - university

Although there were improvements as a result of the application of TQM practices, some problems still occurred, and the high temperatures on the extrusion line resulted in misshapen components. To try to deal with this problem, ALPHA engaged in a joint project with a university research centre to create a software tool to monitor the shape of the components during the extrusion process. The knowledge-based linkage was forged as part of an on-going partnership between the organization's Quality Assurance Group and a group of the university's researchers.

The partnership lasted for three years and involved regular meetings for the mutual sharing of knowledge. A long period of direct observations was required to understand the most frequent problems related to the production process, and to implement trial and error solutions. Some of the university's researchers spent long periods in the company working with ALPHA's employees, which resulted in the transfer of competences and capabilities. The employees working with the researchers were selected on the basis of their competences and desire to acquire and transfer knowledge.

The output was a software tool, based on an algorithm developed by a university researcher (Node D). It is the only system to use measures based on enhanced images. The software was patented by ALPHA . A manager interviewed told us that this ALPHA patent represents an organization-specific resource which is difficult to imitate. The advantages provided by the new tool allowed the component to be monitored throughout the production process, which overcame the problems related to viscosity and high temperatures. It ensured that the component shape was maintained throughout the process through numerical elaboration of signs in real time, and fault detection.

Through this external knowledge-based linkage which allowed sharing of component specific knowledge, ALPHA achieved up to 25% reduction in waste, and significantly improved quality of the final product.

ALPHA - suppliers

The main purpose of a knowledge-based linkage between ALPHA and its suppliers was to share knowledge about the new methods related to the quality management practices. The quality standards introduced by ALPHA meant that suppliers had to provide the right raw materials at the right time. The on-going communication and collaboration allowed suppliers to learn how to implement quality management practices and to monitor the quantity, quality, and delivery of materials. Major reductions in finished goods inventory and more accurate forecasting capability were achieved.

Two aspects should be highlighted:

- the knowledge-based linkage enabled suppliers to learn from ALPHA's best practices and to implement changes. Suppliers introduced new practices (e.g., Kanban in storage and warehousing activities), learnt from knowledge sharing meetings with ALPHA, and became so-called 'talented suppliers' (Smith and Tranfield, 2005);

- suppliers were influenced positively by ALPHA's request to focus on quality, on-time and precise deliveries, resulting in increased flexibility to respond to ALPHA's requirements. This avoided ALPHA wasting time and costs on switching suppliers, and enabled ALPHA to establish knowledge relationships with its suppliers to improve operational performance.

ALPHA - subcontractors

The main aim of the knowledge-based linkage between these organizations was collaborative learning by doing. The subcontractors grew alongside ALPHA, which influenced their economic development, transforming the original micro-organizations into small companies. The impact of these companies' developments was reciprocal. Both parties achieved reductions in inventory levels and response times. The localized learning process that affected ALPHA and its sub-contractors allowed the development of organization-specific technical resources, retention of tacit knowledge within the linkage, avoidance of knowledge obsolescence, and increased knowledge dispersion along the supply chain.

6.7. Conclusion

In this chapter SNA and OWA were applied to a network characterized by tacit knowledge embedded in individuals, and the relations among these individuals. Differently from Chapter 5, the SNA and OWA results do not differ. They provide a similar ranking. This might be because the network is a small one with few direct and indirect ties. Similarly in Chapter 5, we have shown that in a small network with few direct and indirect citations such as the case of NP14, the initial node (in that case P14) is the authority of its network.

We depart from two research questions. First, How do organizations create new knowledge through their internal and external knowledge-based ties? Our case shows that the internal and external knowledge-based ties served to foster the knowledge transfer process and to improve the creation of new knowledge.. Knowledge exploration and exploitation relies on the knowledge accumulating nodes in the knowledge-based ties. In the case study, the strategic decision to invest in the introduction of TQM was based on the central individuals identified by the SNA. They demonstrated better individual performance and, also, were responsible for the company's improved performance. They observed and learned from competitors, and convinced the CEO to invest in training employees in Six Sigma methods to manage and improve quality. As a consequence, new knowledge was developed internally through collaboration among the R&D Department, the Extrusion and Finishing Department, and the Quality Assurance Group. ALPHA is characterized by collaborative working among these three major groups. In addition, the most central nodes acted as bridges and gatekeepers between ALPHA and its strategic partners, such as its suppliers and the university research centre. For instance, the creation of component-specific knowledge to develop a software tool was driven by the knowledge accumulating nodes.

Secondly, what is the impact of managing internal and external knowledge-based ties, on the operational performance? Knowledge creation and transfer among the knowledge-based ties helped to improve operational performance. The intensive knowledge-based ties between ALPHA and its competitors made ALPHA aware of the benefits of investing in

TQM and Six Sigma practices. Their introduction resulted in two different quality outcomes, highlighted by ALPHA employees:

- reducing errors and waste, and monitoring components along the extrusion line – all employees participated in Kanban and Kaizen to improve the quality of the production, and reduce waste and errors. This whole-company collaboration allowed bottlenecks in the work flow to be identified, errors to be eliminated, and improvements made to daily work activities;
- changing the approach to problem solving – this was achieved through the adoption of the Six Sigma approach, which is based on the idea of maintaining control over the entire process at every step using statistical analysis tools to reduce variability. As described above, this approach allowed the development of routines to deal with the measurement of viscosity. In order to create new knowledge by exploiting and exploring the organization's existing capabilities, ALPHA changed its approach to managing and controlling quality. In collaboration with a university research centre, it developed and patented a virtual simulation tool, which was a significant innovation. This software greatly improved the company's operational performance, resulting in dramatic reductions in waste on the extrusion line, savings on costs, and increased customer satisfaction.

The application of OWA weights in this second case differs from the one described in Chapter 5. Here we are dealing with tacit knowledge transferred within a company, to create new knowledge to increase the company's competitive advantage. The network involved three places, 1 for direct ties, and the other two for indirect ties. Given the presence of tacit knowledge we have assumed it is not confined strictly to the boundaries of a direct relation but it cannot be transmitted through several indirect ties, thus an orness value of 0.70 reflects the importance of the first direct and indirect ties. In longer chains of indirect ties (i.e. 10 or more) and in the context of tacit knowledge, we would suggest the same value.

This chapter contributes to the literature on knowledge management in a supply chain and addresses a gap related to knowledge accumulation in the knowledge transfer process. It has some implications, for example:

- the literature on supply chain management focuses mainly on flows of materials and information while the present study examines the role of flows of knowledge among the actors in and members of a supply chain. In doing so, we show that the effective management of these knowledge-based relations positively affects supply chain competitive advantage and contribute to the literature on knowledge management in the supply chain context;
- the identification of the most knowledgeable individuals and their knowledge-based relations provides a useful perspective to understand the process of knowledge accumulation, knowledge transfer and knowledge creation process.

These conclusions are in line with research on knowledge management which emphasizes the need for organizational rather than information technology solutions to foster the processes of knowledge transfer and knowledge creation (Edwards et al., 2005). As a consequence, we can highlight some practical implications.

The practical implications of this study include the provision of insights into the use of SNA and OWA to enable managers to get a better understanding of an organization's resources and capabilities ties. The knowledge linkage map is important at the inter- and intra-organization levels. Within the organization, it is useful to evaluate how these relationships are maintained and the intensity of knowledge transfer among organizations. SNA provides a visual tool to identify the structure of the knowledge ties. The monitoring of knowledge flows using the knowledge linkage map enables a better understanding of the organization-specific conditions surrounding learning and competitive advantage.

Chapter 7. Conclusions, limitations and future works

The objective of this thesis was to analyse the networks of knowledge flows in two different knowledge networks and from two different perspectives, and to assess the role of indirect network ties in the knowledge transfer and creation process. One of the novelties of this research is its application of OWA as an alternative method for analysing networks of knowledge flows to provide a different angle on the study of networks in general. The classical SNA applications were extended in two directions, providing contributions to different research areas. The flows of explicit knowledge in patent citations networks and the flows of tacit knowledge in a company knowledge-transfer network were mapped by means of SNA. Most studies of knowledge flows use network analysis applied to patent citation networks, and a case-study approach and SNA to analyse these phenomena within the firm's boundaries. This thesis goes further by proposing a new approach to studying explicit knowledge flows via patent citations, and tacit knowledge flows via intrafirm and interfirm knowledge-based ties. In both cases indirect ties were considered and ranked using OWA. In particular:

1) In relation to the first research question (what is the role of indirect ties in citation networks?) this thesis shows the role of indirect ties in transferring knowledge. More specifically, SNA was complemented by application of OWA operators to study direct and indirect ties in patent citation networks. Few studies investigate more than three generations of patents and their corresponding citations. Using OWA allowed us to consider several generations as 'places' in the OWA model, and to aggregate them in order to rank indirect citations. Thus, this study adds to our understanding of citation network dynamics by considering several generations of citations and the indirect ties

among them; it is the first study to assess the indirect ties in a network; it also investigates long citation chains and investigates historical citations information. The main advantage of the OWA model is that it allows assessment of the role of indirect citations by considering the distribution of citations in the network, and aggregating several generations of patent citations, something, which is an original contribution. A crucial aspect of any OWA model is the orness level which must be set by the decision-maker. In the context of a patent citations network, the decision-maker could be a network analyst or a policy maker interested in the technological evolution of a specific industry, in our case, renewable energy. To set the most appropriate orness in this thesis we relied on the structural characteristics of the citations network (in the first OWA application). The selected orness reflects the citations distribution, in line with a the studies discussed in Chapter 2. Analysis of the OWA scores and their relation to the SNA results allowed us to rank patents in an alternative way, which provides new insights into the evolution of knowledge. In contrast to the SNA approach, OWA considers the time dimension in the diffusion of the embodied knowledge. The Wilcoxon test confirms that the two rankings differ significantly. This leads to the second important aspect: OWA scores enrich our understanding of knowledge evolution within citation networks. In particular, the relation between an initial patent and its maturity (authority patent) output can be seen as the relation between the 'ancestor' and its 'descendent'. In line with this argument, we proposed that nodes with the highest scores survive for longer than those receiving only a high number of direct citations. The role of the indirect citations received by nodes within a citations network is the subject of much debate in the literature, but few empirical studies address this issue.

2) To answer the second and third research questions introduced in Chapter 1, this thesis maps the internal knowledge-based ties of a company by means of SNA, and the external knowledge-based ties between the company and its supply chain members through a qualitative investigation. In doing so, we show the impact of managing effectively the internal and external knowledge-based ties to foster the knowledge transfer process and to create new knowledge important fro the competitive advantage of the company. Furthermore, in considering the role of indirect ties in the knowledge transfer and knowledge creation processes we applied OWA to the ranking of indirect ties. SNA was complemented by OWA and qualitative in-depth interviews in the case-study company. This provided a rich understanding of the dynamics of knowledge transfer and creation in the supply chain context. The second type of network studied shows different structural characteristics from the citation networks. The orness level selected reflects the idea that in a network, such as in this study, which is characterized by high levels of tacit knowledge, collaboration and problem solving activities, knowledge transfer is not confined strictly to the boundaries of a direct relation but it cannot be transmitted through several indirect ties. The OWA and SNA results provide a similar ranking. This might be because of the presence of few direct and indirect ties (places). Although the two rankings do not differ, we show that OWA weights discriminate better than SNA in attributing a score to individuals considering their indirect ties. This is clear when comparing SNA measures (authority and closeness centrality measures) with OWA scores. This case-study has theoretical and practical implications. It offers insights into the management of knowledge and knowledge relationships among internal organizational members and also external parties. It contributes to debate on the characteristics of organization ties and how to manage the knowledge transfer process within a single organization and between

organizations. It investigated how knowledge is accumulated, shared and applied, to create organization specific knowledge resources that increase and sustain the organization's competitive advantage.

There are two important findings from this research. First, our results show that the SNA and OWA network node rankings differ substantially when a long time lag and several places are considered. This thesis considered 13 years of forward citations that correspond to 10 places to rank. So far, studies considering the further development of initial patents have analysed no more than 3 generations of patents (Harhoff et al., 2003; von Wartburg et al., 2005). In our case the 10 places can be considered as 10 generations. This aspect provides support to use of the proposed OWA operator to rank a long chain of citations. In a supply chain network with few places, the two results do not differ. Second, the two methods presented, SNA and OWA, can be applied in combination to better explain network dynamics.

Limitations and future work

The research has two main limitations. One is related to the patent citation network analysis and the OWA application. The characteristics of the dataset affect the results to a extent, as highlighted in Chapter 2. In order to minimize potential errors, the data were controlled and cleaned in order to have the appropriate number of indirect citations along each place. Thirteen years (2000-2013) was assumed to be a reasonable window time for a young but very active sector such as the renewable energy. However, this time frame could be considered a limitation, and future studies could consider a longer time frame.

Future analyses of citations networks using SNA and OWA would add to our understanding of the evolution of knowledge, and allow investigation and comparison of the contribution of papers, in paper citations networks. In this case, the role of time would still be important. Another possible application of the OWA operator proposed in this thesis would be to study on-line social networks such as Twitter, Linkedin or Researchgate. In this case the focus would be on aspects such as social influence rather than on knowledge flows, in terms of indirect ties among individuals.

The case-study analysis was based on a single case-study and focused on a single unit – Quality Assurance Group. Although this choice is in line with other SNA applications, future work could study more complex organizations, with more nodes and ties. This highlights another limitation of the present research, which is the case-study approach, which means that the findings may not be generalizable. Future work could test our hypothesis on a larger sample. Analysis of multiple case studies using SNA and OWA would provide a deeper understanding of the relationship between the knowledge-based ties at all levels in the supply chain, and the integration of knowledge.

Finally, future works could explore differences in the transmission of tacit and explicit knowledge through a different orness level. In our case, for consistency, we adopted the same value (0.70) in both studies. In Chapter 5 we justified this value following the literature on the structural characteristics of citation networks. In Chapter 6 we assume that indirect ties matter in transferring tacit knowledge, only when the early stages of indirect ties are considered. This might suggest a lower value of α for networks relating to tacit knowledge than for those relating to explicit knowledge. Future works could focus on larger supply chain networks with more indirect ties, as we have demonstrated that OWA is better than SNA in discriminating several levels of indirect ties, particularly in complex networks with hundreds or thousands nodes.

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Appendix Chapter 3

1. The R code for hubs and authorities algorithm

```
A<-read.table("matrice.csv",sep=";",header=T)
a<-matrix(1,10,1)
h<-matrix(1,10,1)
A <- as.matrix(A)

outa <- matrix(0,10,10)
Aut <- t(A) %*% A

k=10
for (i in 1:k)
{
a <- t(Aut) %*% h
n  <- t(a) %*% a
a <- a / sqrt(n[1,1])
h <- Aut %*% a

m <- t(h) %*% h
h <- h / sqrt(m[1,1])

outa[,i] <- a

print(a)
print(h)
}
write.table(outa, "AUT.txt")

## PART HUB

outh <- matrix(0,10,10)

A<-read.table("matrice.csv",sep=";",header=T)

Hub <- A %*% t(A)
a<-matrix(1,10,1)
h<-matrix(1,10,1)
A <- as.matrix(A)
for (i in 1:k)
{
a <- t(Hub) %*% h
n  <- t(a) %*% a
a <- a / sqrt(n[1,1])
h <- Hub %*% a

m <- t(h) %*% h
h <- h / sqrt(m[1,1])
outh[,i] <- h
```

```
print(a)
print(h)
}

write.table(outh,"HUB.txt")
```

Appendix Chapter 5

1. SNA results

Network and connectivity analysis of the network built on P1 (NP1) -20000927-00325408

P1 is the European patent published by the Japanese Kaneka Corporation under the title 'Photovoltaic module' (IPC: B32B17/10; H01L31/0203). NP1 is very small network comprising five vertices (patents) and four arcs (citations). NP1 characteristics are given in Table 5.7.NP1.

Table 5.7.NP1. Characteristics

Number of vertices (n)	**5**
	Arcs
Total number of lines	4
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.16
Average degree	1.60

In-degree centrality (Figure 5.1.NP1, Table 5.8.NP1) – P1 is the only vertex with incoming arcs, thus, this is the only vertex with an in-degree value.

Table 5.8.NP1. In-degree and out-degree centrality measures of NP1

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	1 (P1)	4	20000927-00325408	2	1	20120510-79559870
2	5	0	20110111-64256374	5	1	20110111-64256374
3	4	0	20110118-64755055	4	1	20110118-64755055
4	**3**	**0**	20091126-71078943	3	1	20091126-71078943
5	2	0	20120510-79559870	1 (P1)	0	20000927-00325408

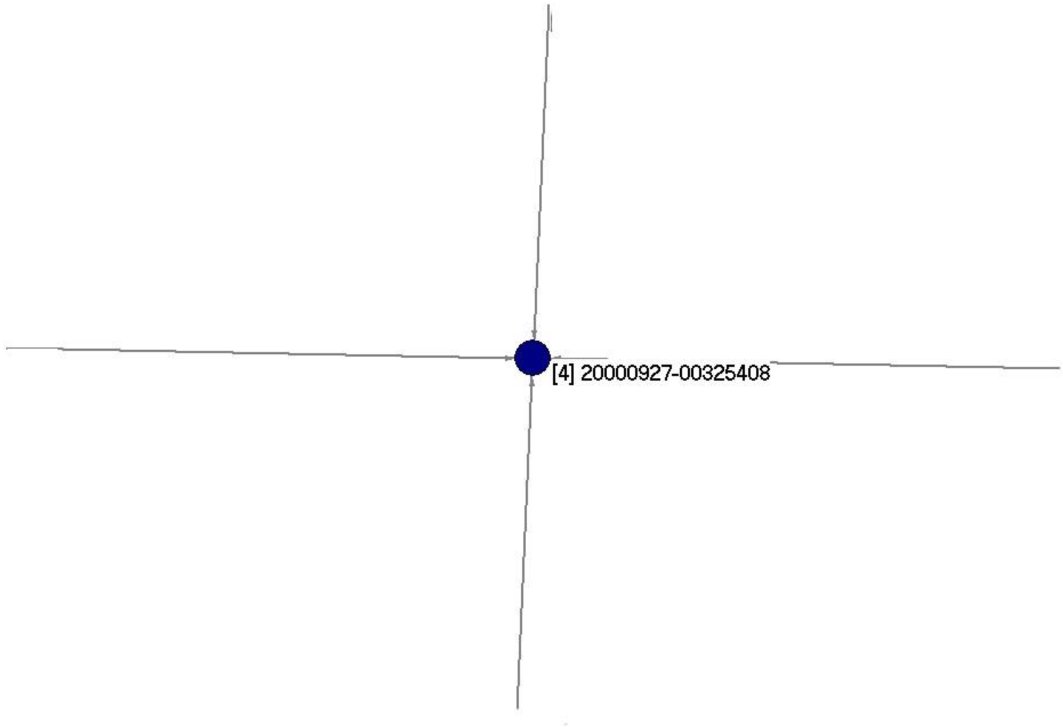

Figure 5.1.NP1. In-degree centrality of NP1

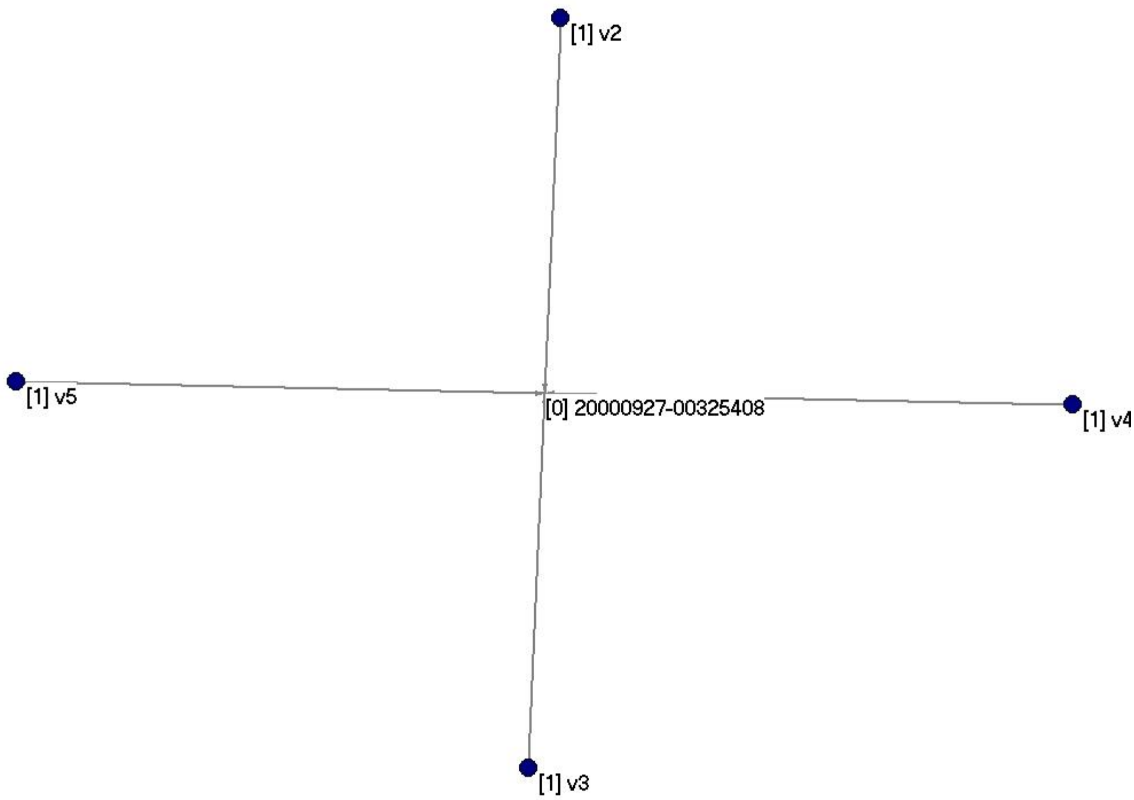

Figure 5.2.NP1. Out-degree centrality of NP1

Closeness centrality (Figure 5.3.NP1, Table 5.9.NP1) – For closeness to other patents, P1 has the highest value (1); the values of the other patents are the same (0.57).

Table 5.9.NP1. Closeness centrality of NP1

Rank	Vertex	Value	Id (Label)
1	1 (P1)	1.00	20000927-00325408
2	5	0.57	20110111-64256374
3	4	0.57	20110118-64755055
4	3	0.57	20091126-71078943
5	2	0.57	20120510-79559870

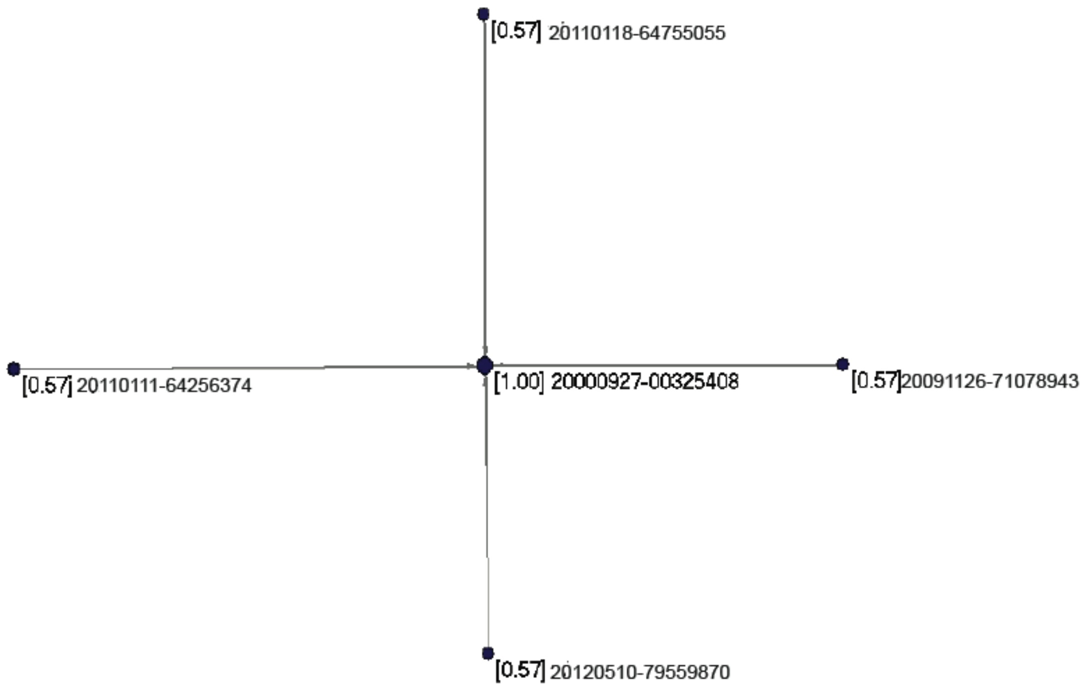

Figure 5.3.NP1. Closeness centrality of NP1

Authority weights (Figure 5.4.NP1, Table 5.10.NP1) – Given the nature of this small citations network, P1 is the only authority.

Table 5.10.NP1. The authority patent of NP1

Rank	Vertex	Value	Id (Label)
1	1 (P1)	1	20000927-00325408
2	5	0	20110111-64256374
3	4	0	20110118-64755055

4	3	0	20091126-71078943
5	2	0	20120510-79559870

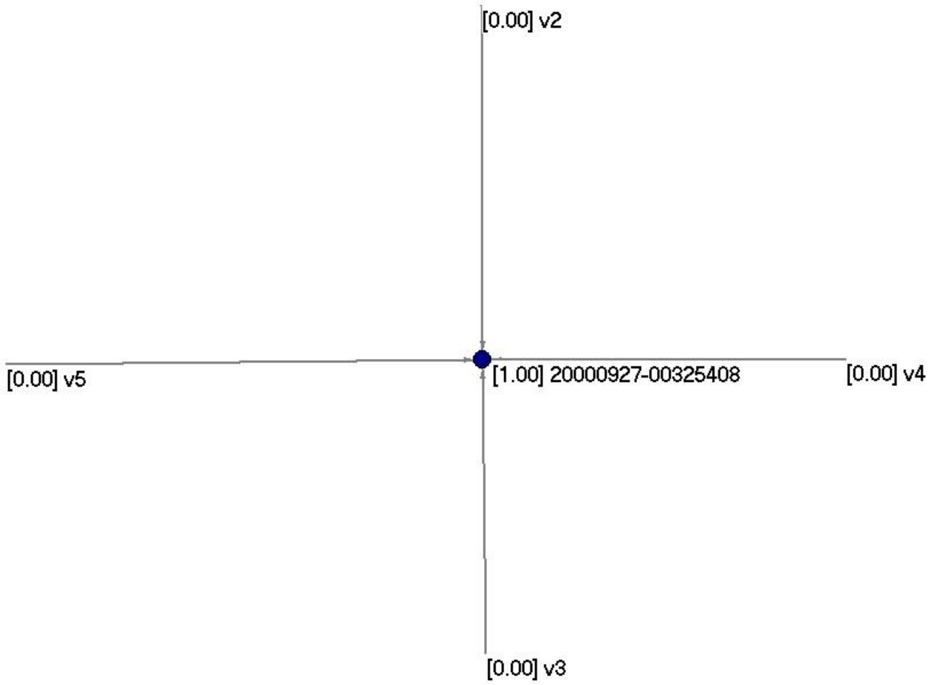

Figure 5.4.NP1. The authority patents of NP1

<u>*Hub weights (Figure 5.5.NP1, Table 5.11.NP1)*</u> – The best developments of P1 are the other patents in NP1 which are of equal importance.

- vertex 3 is a patent owned by the Japanese company Mitsubishi, entitled 'Solar panel and production method therefor';
- vertex 5 is a patent owned by the German company Eisenmann AG, entitled 'Photovoltaic module e.g. thin layer solar module, has photovoltaic cells covered on transparent support substrate by side of metallic covering layer, which is designed as metal foil';
- vertex 4 is patent owned by the Japanese company Mitsubishi, entitled 'Solar panel and production method thereof';

- vertex 2 is a patent owned by four private Italian inventors, entitled 'Photovoltaic panel, relative production process and plant for carrying out such a process'.

Table 5.11.NP1. The hub patents of NP1

Rank	Vertex	Value	Id (Label)
1	3	0.50	20110111-64256374
2	5	0.50	20120510-79559870
3	4	0.50	20110118-64755055
4	2	0.50	20091126-71078943

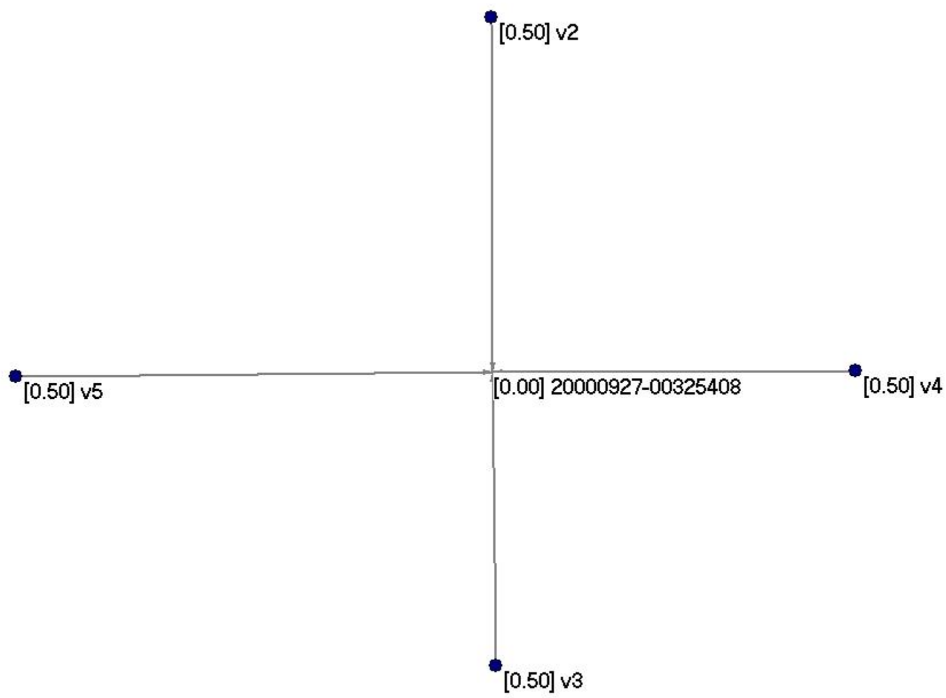

Figure 5.5.NP1. The hub patents of NP1

<u>*SPC (Figure 5.6.NP1, Table 5.12.NP1*</u>) – The technological trajectory of NP1 is characterized by the five patents already described.

Table 5.12.NP1 vertices on main path [flow] of NP1

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000927-00325408
2	2	1	20091126-71078943

3	3	1	20110111-64256374
4	4	1	20110118-64755055
5	5	1	20120510-79559870

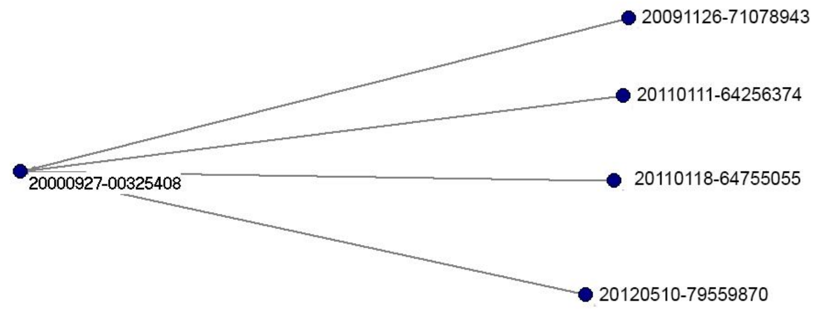

Figure 5.6.NP1. SPC of NP1

Network and connectivity analysis of network built on P3 (NP3)- 20001220-00495792

P3 is the European patent published by the Japanese Kaneka Corporation, under the title 'Method of fabricating thin-film photovoltaic module'. The characteristics of NP3 are given in Table 5.5NP3. It includes one loop which we removed before calculating the network measures.

Table 5.7.NP3. Characteristics

Number of vertices (n)	**99**
	Arcs
Total number of lines	116
Number of loops	1
Number of multiple lines	0
Density [loops allowed]	0.01
Average degree	2.34

In-degree centrality (Figure 5.1.NP3, Table 5.8.NP3) - Figure 5.1.NP3 depicts NP3 according to the in-degree centrality measure, and the corresponding values are displayed in Table 5.8.NP3. According to the in-degree centrality the first patent, the most cited, in NP3 is vertex 3, while vertex 1 (P3) occupies the 4th position. The most cited patent was published in the US in 2007 with the title 'Method of manufacturing thin film photovoltaic modules', the applicant is the BP Corporation North America Inc.

Table 5.8.NP3. Top 10 in-degree and out-degree centrality values of NP3

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	3	27	20070821-62398637	76	5	20120306-75837741
2	6	17	20080515-29436452	41	4	20101216-75416781
3	4	12	20071221-00078925	95	3	20121218-74910580
4	1 (P3)	10	20001220-00495792	60	2	20110621-71003687
5	2	7	20051215-07096762	6	2	20080515-29436452
6	60	5	20110621-71003687	27	2	20100602-73385677
7	13	4	20090813-70444497	24	2	20100311-72844604
8	18	4	20091231-72194927	90	2	20120904-72749014
9	8	4	20090129-69275079	44	2	20101230-75279517
10	7	3	20080611-19246728	42	2	20101216-75427617

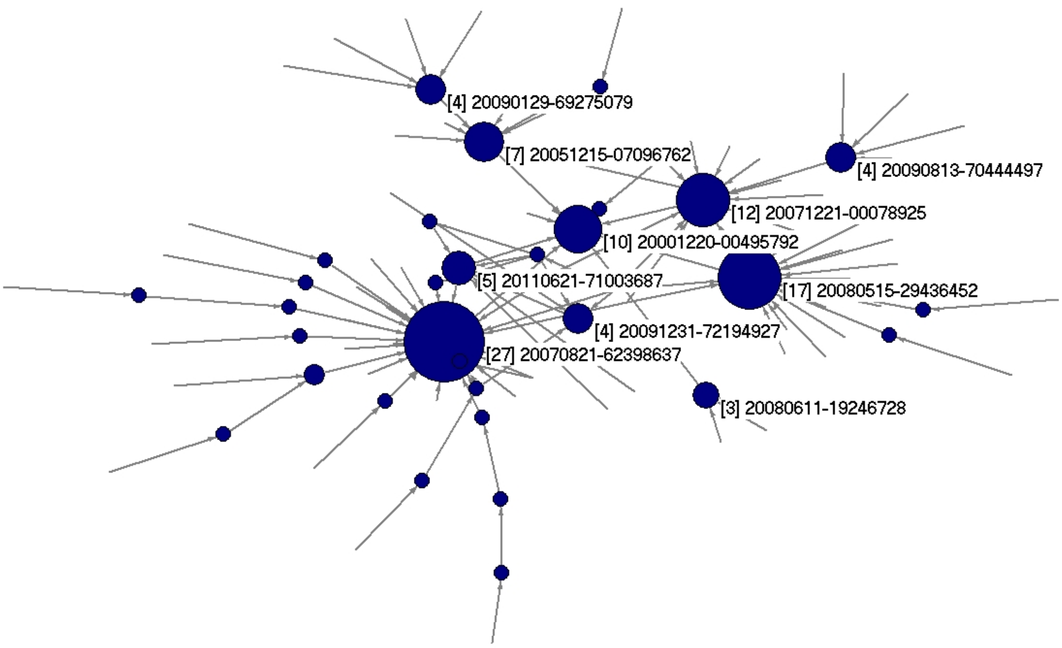

Figure 5.1.NP3. In-degree centrality of NP3

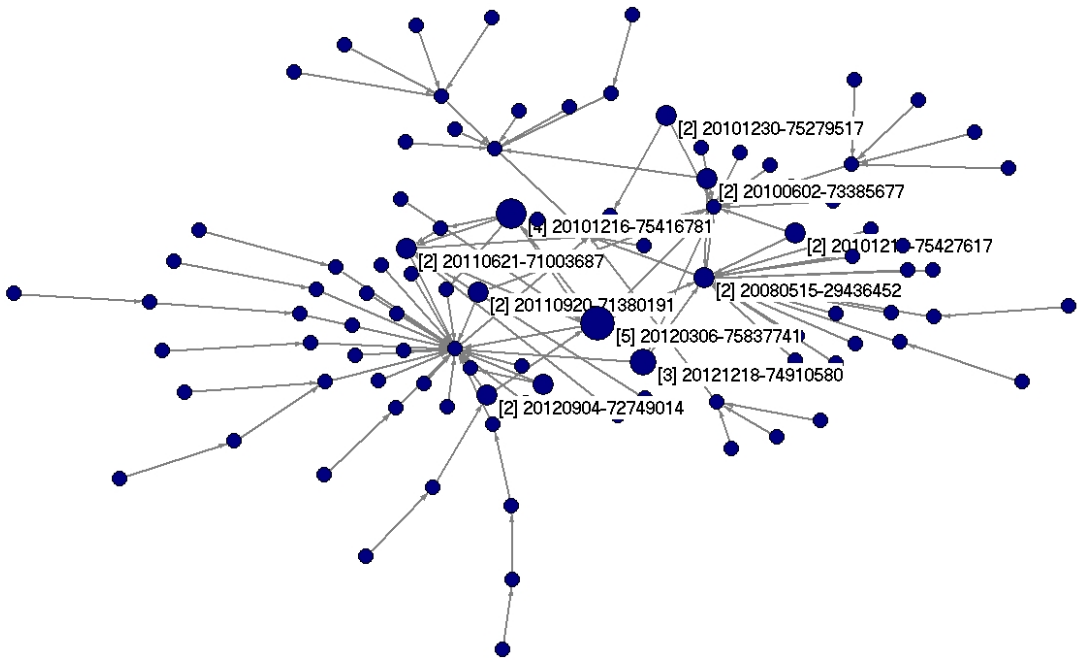

Figure 5.2.NP3. Out-degree centrality of NP3

Closeness centrality (Figure 5.3.NP3; Table 5.9.NP3) – P3 is the first among the top 10 patents according to the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all others. The concept is more intuitively explained by Figure 5.3.NP3, which shows P3 lying at the centre of the surrounding clusters.

Table 5.9.NP3. Top 10 closeness centrality measures of NP3

Rank	**Vertex**	**Value**	**Id (Label)**
1	1 (P3)	0.45	20001220-00495792
2	3	0.43	20070821-62398637
3	76	0.38	20120306-75837741
4	6	0.38	20080515-29436452
5	60	0.37	20110621-71003687
6	95	0.37	20121218-74910580
7	4	0.37	20071221-00078925
8	67	0.35	20110920-71380191
9	2	0.34	20051215-07096762
10	7	0.32	20080611-19246728

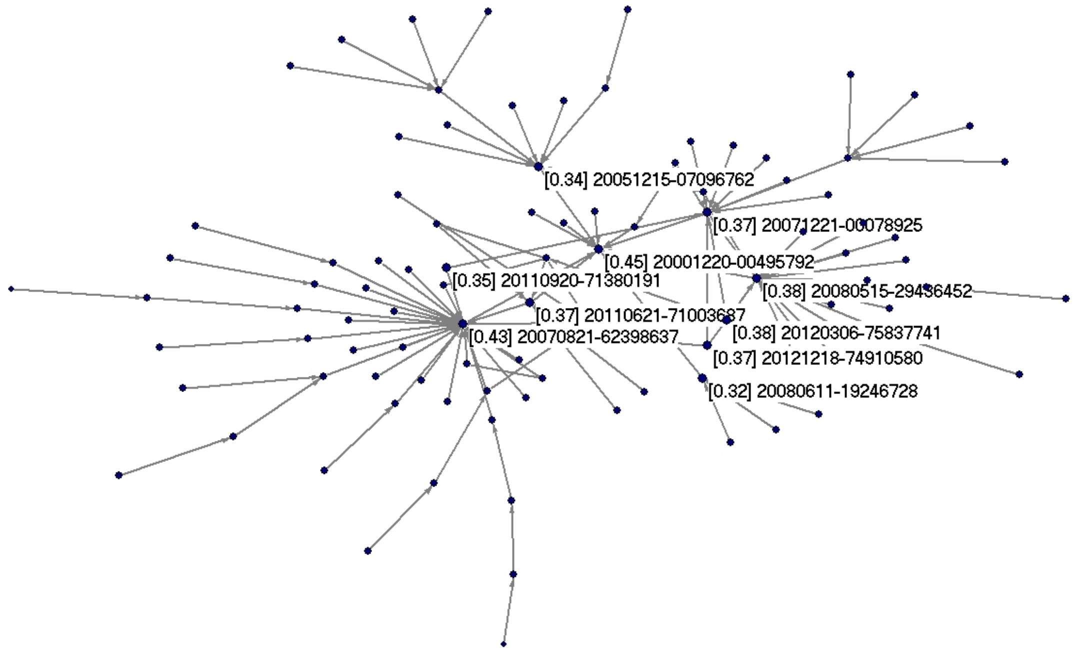

Figure 5.3.NP3. Closeness centrality of NP3

<u>Authority weights (Figure 5.4.NP3, Table 5.10.NP3)</u> – we identify the first ten most authority patents.

P3 occupies fifth place in the ranking:

- the most authority patent, vertex 3, is also the most cited according to the in-degree centrality;
- the second most authority patent, vertex 6, was published in 2008, the applicant is a UK company Exitech Ltd, a manufacturer of high-power pulsed laser-based systems for industrial materials processing applications. The title of the patent is 'Method and apparatus for laser beam alignment for solar panel scribing';
- the third one, vertex 4, belongs to the same owner as the previous patent, it was published in 2007 and deals with a similar technology. The title is 'Process for laser scribing'.

- the fourth most authority patent, vertex 18, was published in 2009 in the US, the owner is the company Applied Material Inc. It deals with technology similar to the previous patents, the title is 'Dynamic scribing alignment for laser scribing, welding or any patterning system'.
- the fifth is P3.

Table 5.10.NP3. The authority patents of NP3

Rank	Vertex	Value	Id (Label)
1	3	0.94	20070821-62398637
2	6	0.23	20080515-29436452
3	4	0.23	20071221-00078925
4	18	0.10	20091231-72194927
5	1 (P3)	0.06	20001220-00495792
6	41	0.05	20101216-75416781
7	47	0.03	20110208-71008390
8	2	0.01	20051215-07096762

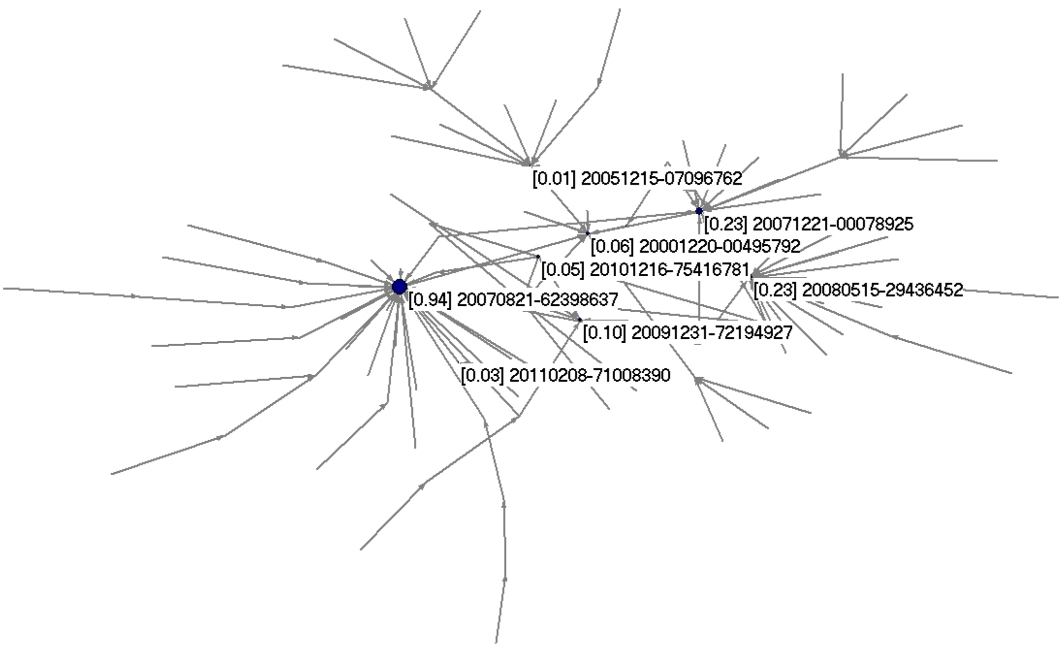

Figure 5.4.NP3. The authority patents of NP3

<u>*Hub weights (Figure 5.5.NP3; Table 5.11.NP3)*</u> - In Table 5.11.NP3 we highlight the 10 best developments of the most authority patents. These are the most recent patents which were published mostly in 2011 and 2012. Focusing on the first five hubs:

6. the first best development (vertex 76) is the US patent owned by the company Applied Materials Inc., with the title 'Method and related systems for thin film laser scribing devices';
7. the second hub (vertex 95) is the US patent owned by the company Applied Materials Inc., with the title 'Process to remove metal contamination on a glass substrate';
8. the third hub (vertex 67) is the patent entitled 'Method and apparatus for forming the separating lines of a photovoltaic module with series-connected cells', published in 2009, owned by German inventor Walter Psyk;
9. the fourth patent (vertex 90) is the patent entitled 'Laser material removal methods and apparatus', owned by the company Applied Materials Inc.;
10. the fifth hub (vertex 60) is the patent entitled 'Process for laser scribing', published in US by a UK company, Exitech Ltd.

Table 5.11.NP3. Top 10 hub weights of NP3

Rank	**Vertex**	**Value**	**Id (Label)**
1	76	0.29	20120306-75837741
2	95	0.26	20121218-74910580
3	67	0.21	20110920-71380191
4	90	0.19	20120904-72749014
5	60	0.18	20110621-71003687
6	66	0.18	20110920-70963786
7	29	0.18	20100608-67399182
8	59	0.18	20110621-58817246
9	58	0.18	20110607-72844891
10	12	0.18	20090610-70400694

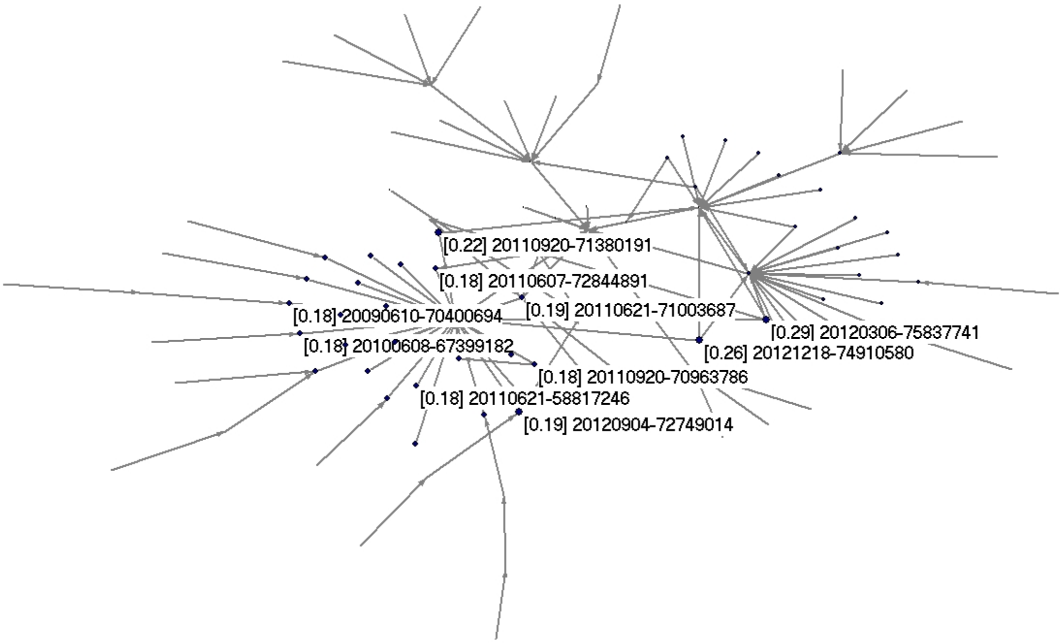

Figure 5.5.NP3. The hub patents of NP3

SPC (Figure 5.6.NP3; Table 5.12.NP3) - This section presents the results of the SPC algorithm. Figure 5.6.NP3 depicts the 'main path' emerging in NP3, it identifies seven patents that are listed in Table 5.12.NP3. According to the SPC results, the technological trajectory shows P3 as endpoint and vertex 76 as startpoint. It has been identified previously as the first best hub in the network. Along the trajectory there are five patents already described among the top authority patents or as their best developments (vertex 3, 60, 41, 76, 18, 34).

Table 5.12.NP3. Vertices on main path SPC [flow] of NP3

Rank	Vertex	Cluster	Id (Label)
1	1 (P3)	1	20001220-00495792
2	3	1	20070821-62398637
3	60	1	20110621-71003687
4	41	1	20101216-75416781
5	76	1	20120306-75837741
6	18	1	20091231-72194927
7	34	1	20101028-74934241

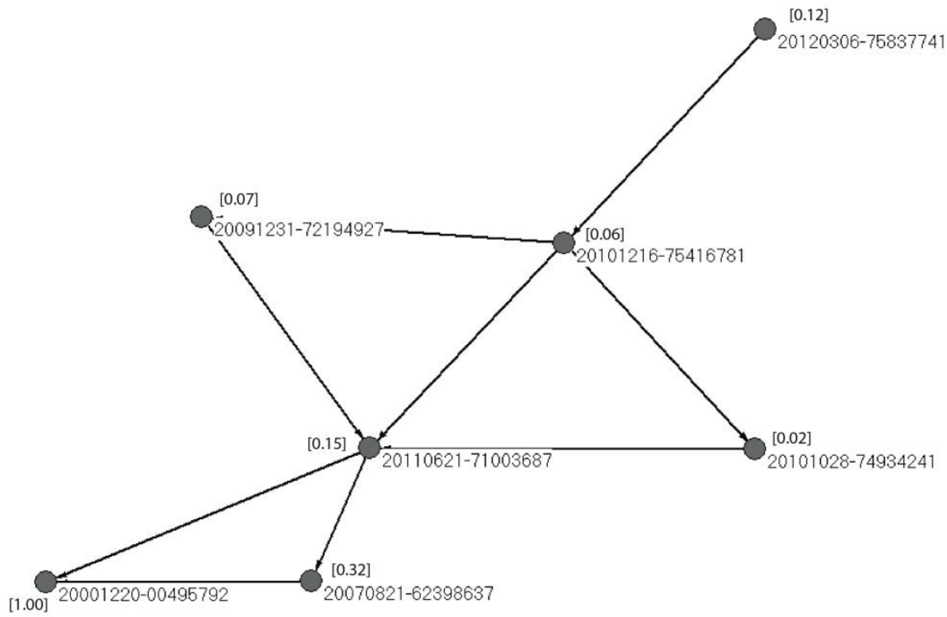

Figure 5.6.NP3. SPC of NP3

<u>Network and connectivity analysis of network built on P4 (NP4) - 20000719-00556153</u>

P4 is the European patent registered at the EPO in 2000 by a Japanese applicant, the company Canon KK, with the title 'Solar cell module and power generation apparatus'. NP4 characteristics are given in Table 5.7.NP4.

Table 5.7.NP4. Characteristics

Number of vertices (n)	**18**
	Arcs
Total number of lines	17
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.05
Average degree	1.8

In-degree centrality (Figure 5.1.NP4; Table 5.8.NP4) - Figure 5.1.NP4 depicts the network built on P4 (NP4) according to the in-degree centrality values of its nodes. The first most cited patent in NP4 is P4 followed by vertex 3, published by two applicants with the title 'Construction products with integrated photovoltaics'; a third patent, vertex 6, owned by American Solar Technologies with the title 'Solar electric module', a fourth patent, vertex 5, owned by the same company and published in the same year, with the title 'Solar electric module with redirection of incident light'. The 5th patent receiving 1 citation is vertex 13, published by 10 applicants with the title 'Concentrator solar cell modules with light concentrating articles comprising ionomeric materials'.

Table 5.8.NP4. In-degree and out-degree centrality values of NP4

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	1 (P4)	9	20000719-00556153	3	1	20030814-01704494
2	3	2	20030814-01704494	18	1	20121227-79785659
3	6	2	20080814-00098127	17	1	20120802-78985660
4	5	2	20080814-00098113	16	1	20111013-77819147
5	13	1	20100603-73577742	7	1	20081224-68673370
6	17	1	20120802-78985660	15	1	20110714-75767775

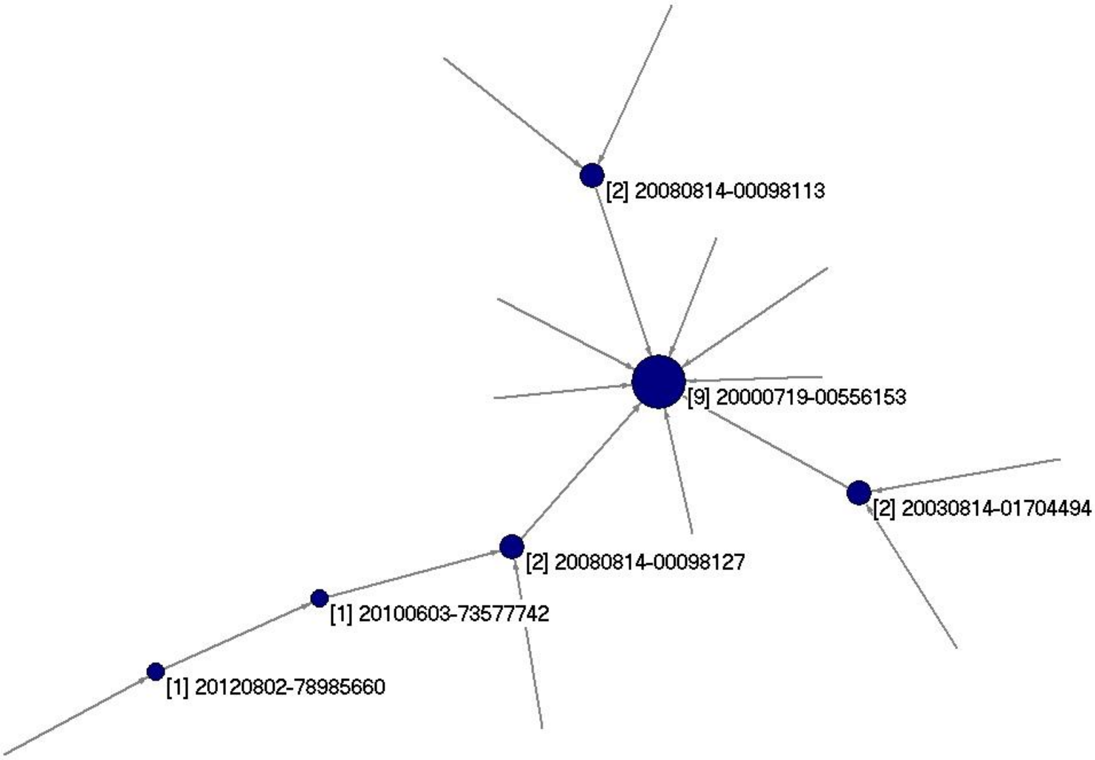

Figure 5.1.NP4. In-degree centrality of NP4

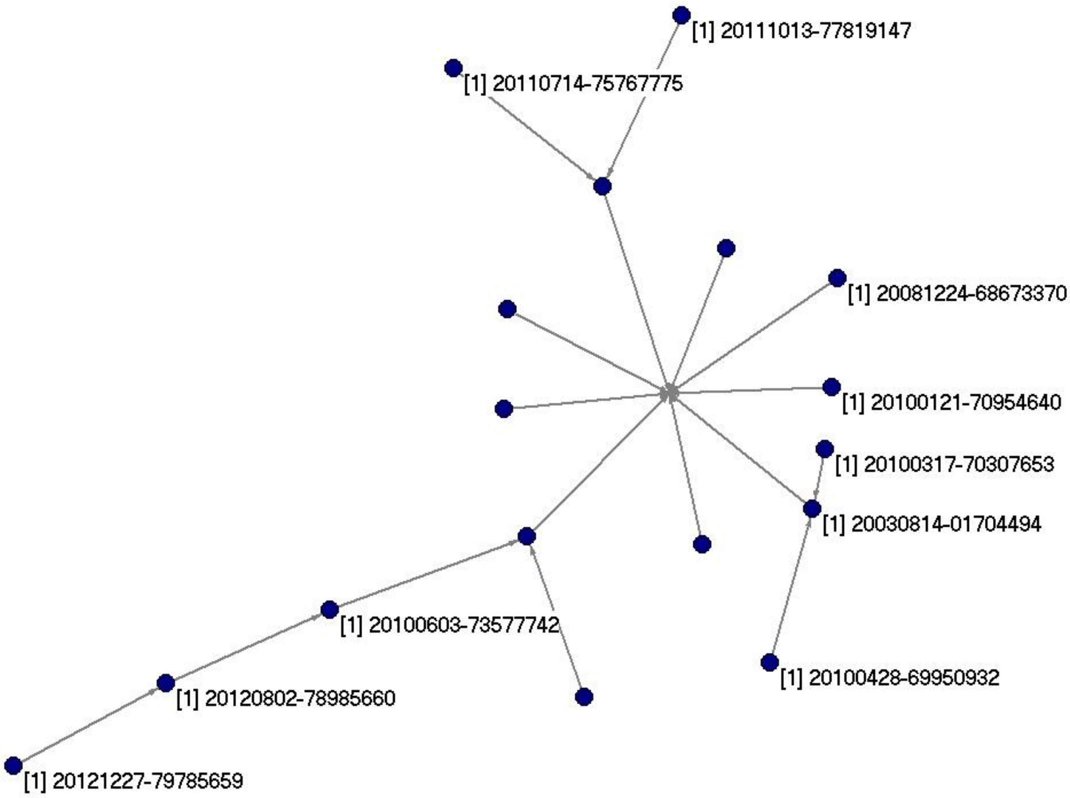

Figure 5.2.NP4. Out-degree centrality of NP4

Closeness centrality (Figure 5.3.NP4; Table 5.9.NP4) – P4 also has the highest closeness centrality value. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP4, which shows P4 lying at the centre of the surrounding clusters.

Table 5.9.NP4. Top 10 closeness centrality values of NP4

Rank	Vertex	Value	Id (Label)
1	1 (P4)	0.61	20000719-00556153
2	6	0.47	20080814-00098127
3	3	0.42	20030814-01704494
4	5	0.42	20080814-00098113
5	7	0.39	20081224-68673370
6	2	0.39	20020313-00356802
7	10	0.39	20100121-70954640
8	4	0.39	20050127-06373518
9	9	0.39	20091015-00091711
10	8	0.39	20090917-70020946

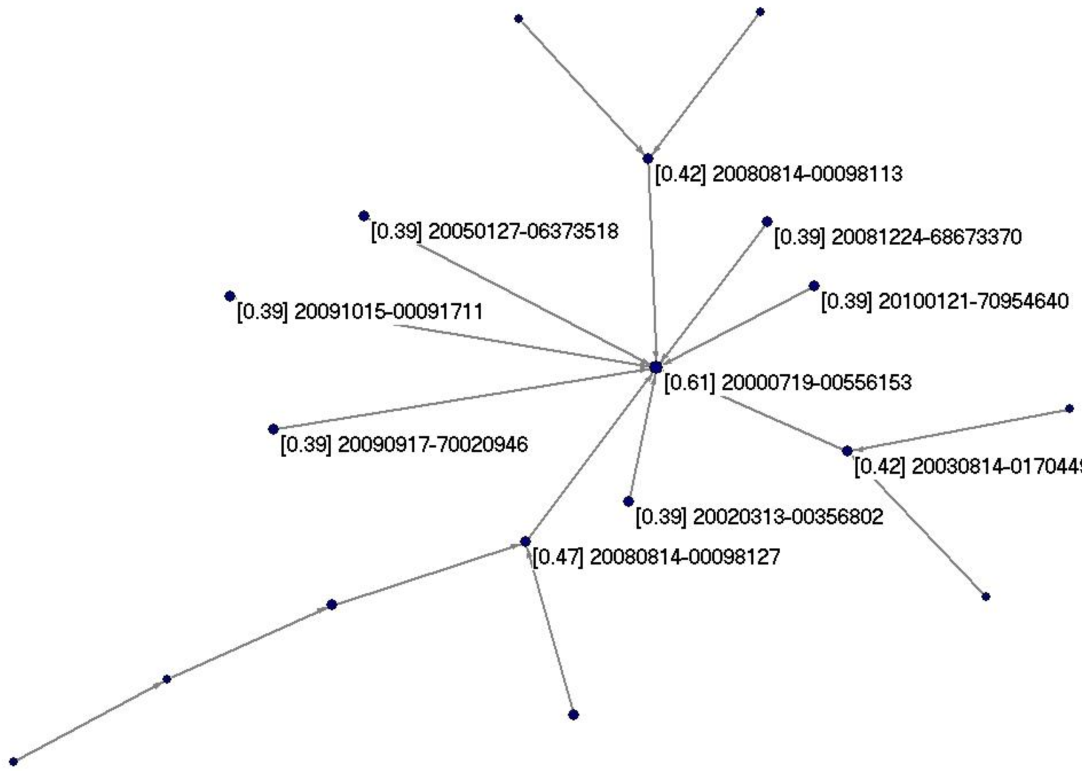

Figure 5.3.NP4. Closeness centrality of NP4

Authority weights (Figure 5.4.NP4, Table 5.10.NP4) - The values of authority weights are worth noting. P4 obtained the highest value (1) followed by only three other patents with a smaller value 0.0024. Since we retain values to two decimal places, we only report P4 in the corresponding table and figure.

Table 5.10.NP4. The authority patent of NP4

Rank	Vertex	Value	Id
1	1 (P4)	1	20000719-00556153

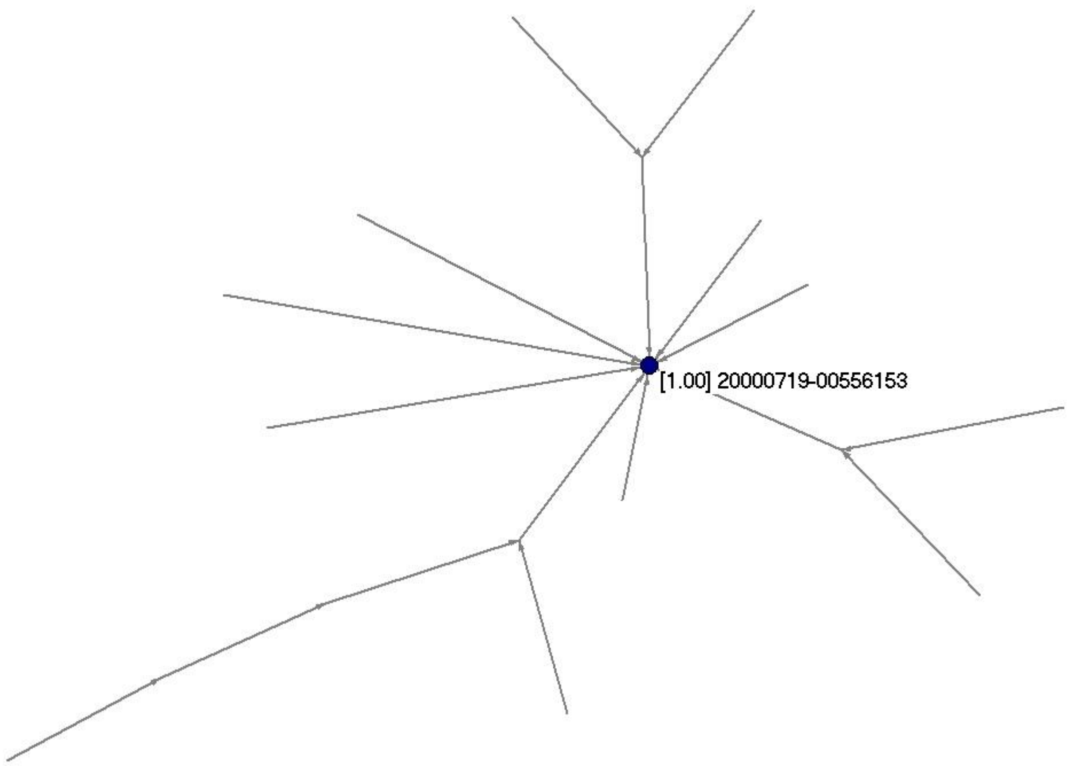

Figure 5.4.NP4. The authority patent of NP4

Hub weights (Figure 5.5.NP4, Table 5.11.NP4) - In terms of best developments of the core innovation, the nine hubs identified are equally important, all having the same value, 0.33.

- The first best development is vertex 3, already described as the second most cited patent in NP4;

- the second best development is owned by the same company, the Japanese Canon KK, and refers to the same technology, but was published in 2008, thus, it can be argued that is an improvement on the original patent P4;
- the third hub (vertex 6) is a patent owned by the American Solar Technologies company, entitled 'Solar electric module';
- the fourth (vertex 2) was published in the EU by the Japanese company Sanyo, with the title 'Solar cell module';
- the fifth hub (vertex 5) is a patent published in 2008 by the American Solar Technologies company, with the title 'Solar electric module with redirection of incident light'. Note that the relationship between hubs and authorities is a reinforcing relationship and is particular evident in a small network like NP4.

Table 5.11.NP4. The hub patents of NP4

Rank	**Vertex**	**Value**	**Id (Label)**
1	3	0.33	20030814-01704494
2	7	0.33	20081224-68673370
3	6	0.33	20080814-00098127
4	2	0.33	20020313-00356802
5	5	0.33	20080814-00098113
6	10	0.33	20100121-70954640
7	4	0.33	20050127-06373518
8	9	0.33	20091015-00091711
9	8	0.33	20090917-70020946
10	3	0.33	20030814-01704494

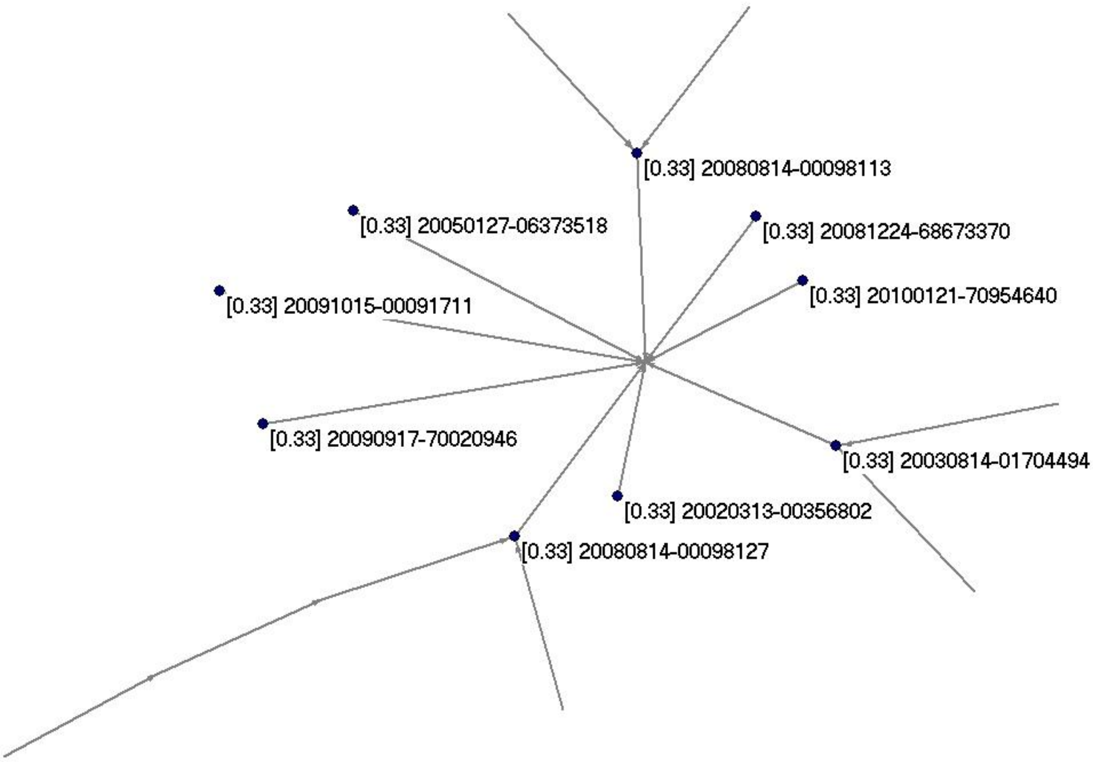

Figure 5.5.NP4. The hub patents of NP4

<u>*SPC (Figure 5.6.NP4, Table 5.12.NP4)*</u> – The SPC algorithm highlights all patents in NP4 as belonging to its technological trajectory. This goes from the most recent patent '20121227-79785659', owned by the German company Evonik Roehm GMBH, with the title 'Polymeric substrate material for physical and chemical vapour deposition processes, containing an adhesion-promoting polymeric layer, and the use thereof for producing concentrators of solar radiation', to P4.

Table 5.12.NP4. Vertices on main path SPC [flow] of NP4

Rank	Vertex	Cluster	Id (Label)
1	1(P4)	1	20000719-00556153
2	2	1	20020313-00356802
3	3	1	20030814-01704494
4	4	1	20050127-06373518
5	5	1	20080814-00098113
6	6	1	20080814-00098127
7	7	1	20081224-68673370
8	8	1	20090917-70020946

9	9	1	20091015-00091711
10	10	1	20100121-70954640
11	11	1	20100317-70307653
12	12	1	20100428-69950932
13	13	1	20100603-73577742
14	14	1	20110601-72693208
15	15	1	20110714-75767775
16	16	1	20111013-77819147
17	17	1	20120802-78985660
18	18	1	20121227-79785659

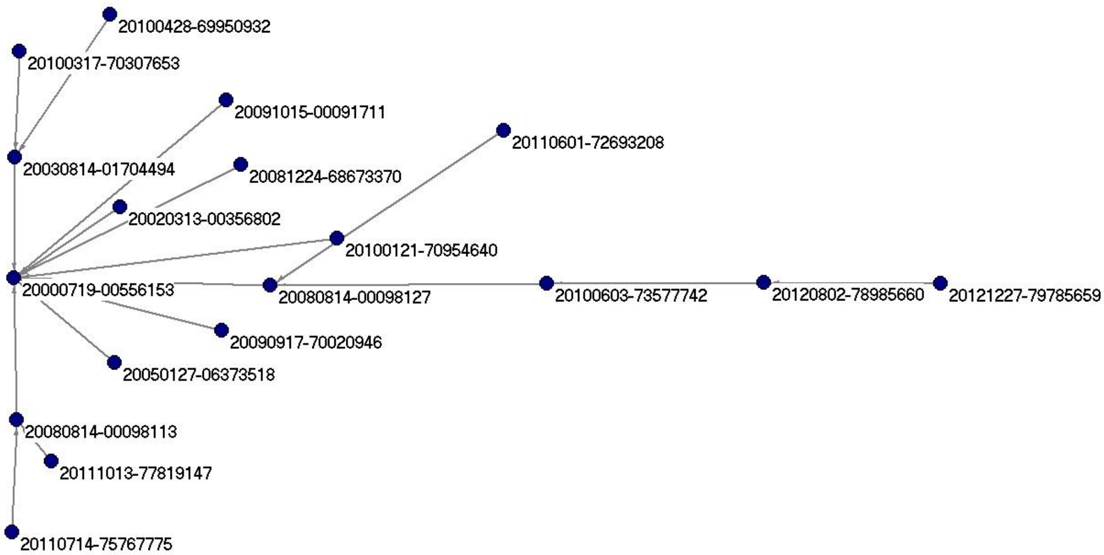

Figure 5.6.NP4. SPC of NP4

__Network and connectivity analysis of network built on P5 (NP5) - 20001129-00575154__

P5 is a European patent owned by the German company Angewandte Solarenergie GMBH, entitled 'Solar cell with a protection diode and its manufacturing method'. NP5 is comprised of 123 vertices, 165 arcs and 1 loop which was removed to conduct the network analysis. NP5 characteristics are given in Table 5.7.NP5.

Table 5.7.NP5. Characteristics

Number of vertices (n)	**123**

	Arcs
Total number of lines	165
Number of loops	1
Number of multiple lines	0
Density [loops allowed]	0.01
Average degree	2.68

In-degree centrality (Figure 5.1.NP5, Table 5.8.NP5) - Results show that the most cited patent is vertex 3 with in-degree centrality value of 16. It is a US patent published in 2004 and owned by the company Emcore Corporation working on compound semiconductor-based products for the telecom, broadband, broadcast, defence and homeland security. The title is 'Apparatus and method for optimizing the efficiency of a bypass diode in multijunction solar cells'. According to the in-degree centrality values, P5 is the 6th most cited patent with a value equal to 8.

Table 5.8.NP5. Top 10 in-degree and out-degree centrality values of NP5

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	3	16	20040120-67961951	56	5	20110614-74510857
2	11	14	20080603-66940051	114	4	20121009-74622803
3	4	13	20050308-61884858	110	4	20120911-72591811
4	10	12	20080327-67419190	65	4	20110920-75759490
5	8	11	20061003-62397494	30	3	20100720-66529088
6	1 (P5)	8	20001129-00575154	112	3	20120911-75833797
7	15	7	20090326-70041113	111	3	20120911-74417979
8	39	6	20101130-64676642	102	3	20120807-73440642
9	17	6	20090806-71068063	96	3	20120529-79742171
10	34	6	20100914-73341968	32	3	20100902-74387617

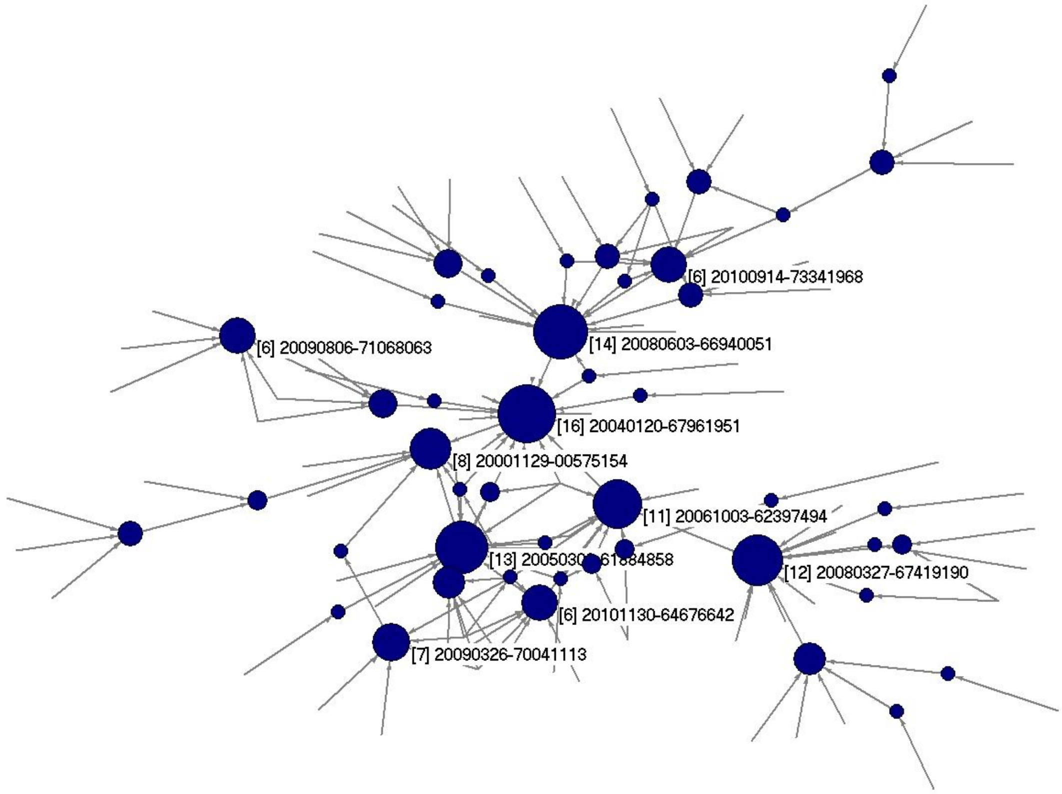

Figure 5.1.NP1. In-degree centrality of NP5

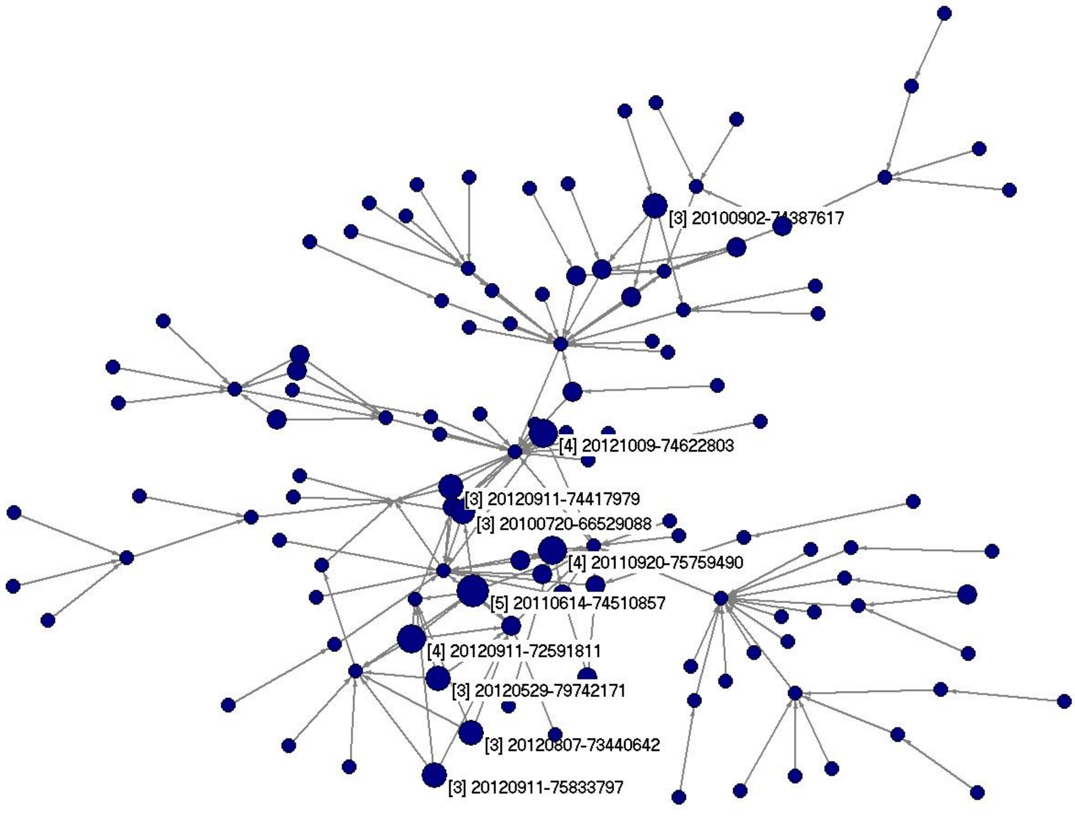

Figure 5.2.NP1. Out-degree centrality of NP5

Closeness centrality (Figure 5.3.NP5, Table 5.9.NP5) - P5 occupies fifth position in the top ten patents ranked according to closeness centrality. The first is again vertex 3, the most cited patent.

Table 5.9.NP5. Top 10 closeness centrality values of NP5

Rank	Vertex	Value	Id (Label)
1	3	0.37	20040120-67961951
2	8	0.35	20061003-62397494
3	11	0.32	20080603-66940051
4	114	0.31	20121009-74622803
5	1 (P5)	0.31	20001129-00575154
6	30	0.30	20100720-66529088
7	111	0.30	20120911-74417979
8	75	0.30	20120110-71096133
9	13	0.30	20081111-59891583
10	10	0.29	20080327-67419190

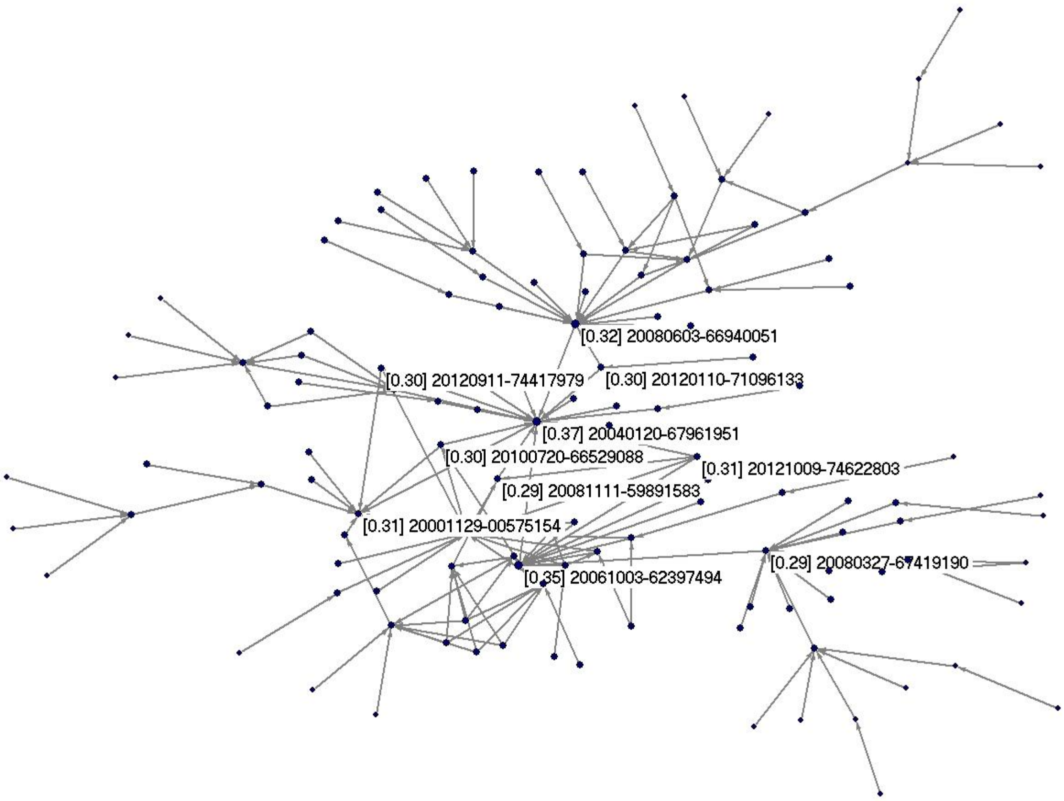

Figure 5.3.NP1. Closeness centrality of NP5

Authority weights (Figure 5.4.NP5, Table 5.10.NP5) - The first five most authority patents are:

- vertex 4, a patent owned by the American Emcore Corporation with the title 'Apparatus and method for integral bypass diode in solar cells';
- vertex 3, already mentioned as the most cited;
- vertex 8, published in 2006 by the American Emcore Corporation with the title 'Solar cell having an integral monolithically grown bypass diode';
- P5;
- vertex 15, published in 2009 by the American Emcore Corporation with the title 'Barrier layers in inverted metamorphic multijunction solar cells'.

Table 5.10.NP5. Top 10 authority patents of NP5

Rank	**Vertex**	**Value**	**Id (Label)**
1	4	0.63	20050308-61884858
2	3	0.55	20040120-6796195
3	8	0.48	20061003-62397494
4	1 (P5)	0.16	20001129-00575154
5	15	0.10	20090326-70041113
6	39	0.09	20101130-64676642
7	11	0.09	20080603-66940051
8	35	0.09	20100923-74527564
9	13	0.08	20081111-59891583
10	46	0.06	20110201-65937030

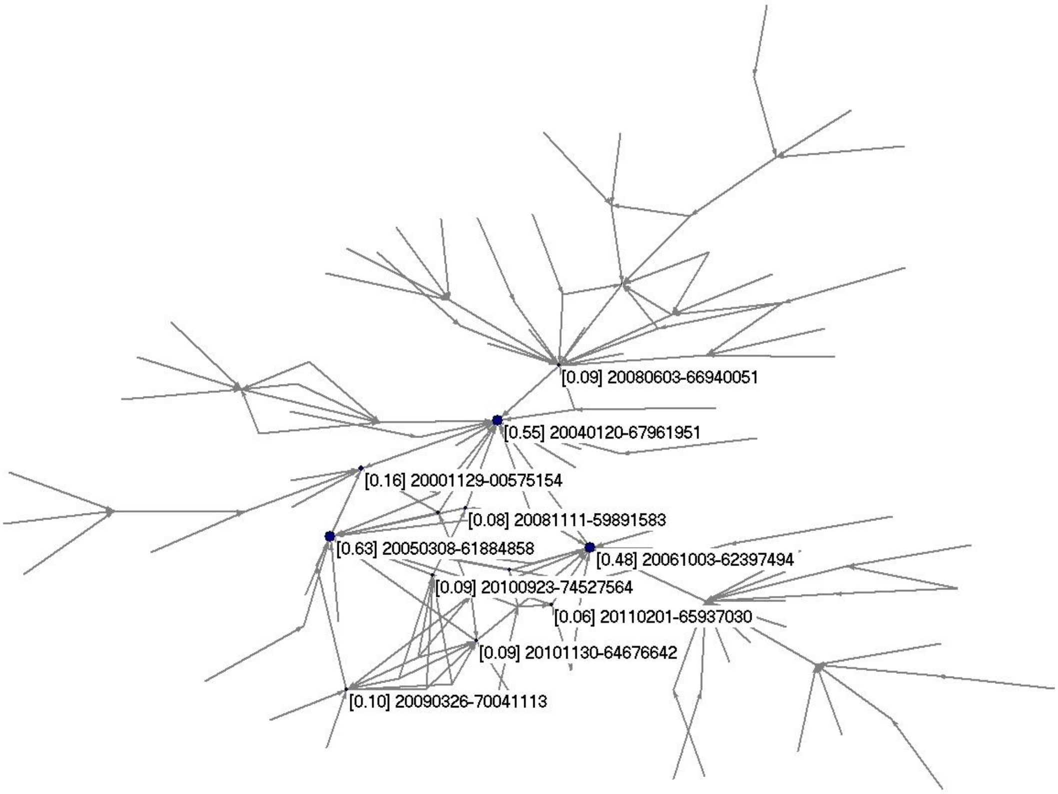

Figure 5.4.NP5. The authority patents of NP5

<u>*Hub weights (Figure 5.5.NP5, Table 5.11.NP5)*</u> – The best developments of the core authority patents in NP5 are listed in Table 5.12.NP5. The top five are:

- vertex 114, published in US by the American Boeing Corporation, with the title 'Solar cell assembly';
- vertex 30, published in US by the Emcore Corporation with the title 'Apparatus and method for integral bypass diode in solar cells';
- vertex 111, published in US, by the Emcore Corporation, with the title 'Multijunction solar cell with a bypass diode';
- vertex 65, also published in US by the Emcore Corporation, with the title 'Externally modulated laser optical transmission system with feed forward noise cancellation';

- vertex 13, published in US by the Emcore Corporation and three private inventors, with the title 'Solar cell having an integral monolithically grown bypass diode'.

Table 5.11.NP5. Top 10 hub patents of NP5

Rank	Vertex	Value	Id (Label)
1	114	0.37	20121009-74622803
2	30	0.28	20100720-66529088
3	111	0.28	20120911-74417979
4	65	0.26	20110920-75759490
5	13	0.25	20081111-59891583
6	12	0.23	20080812-67676273
7	46	0.23	20110201-65937030
8	41	0.23	20101207-62919728
9	39	0.23	20101130-64676642
10	33	0.23	20100907-66165049

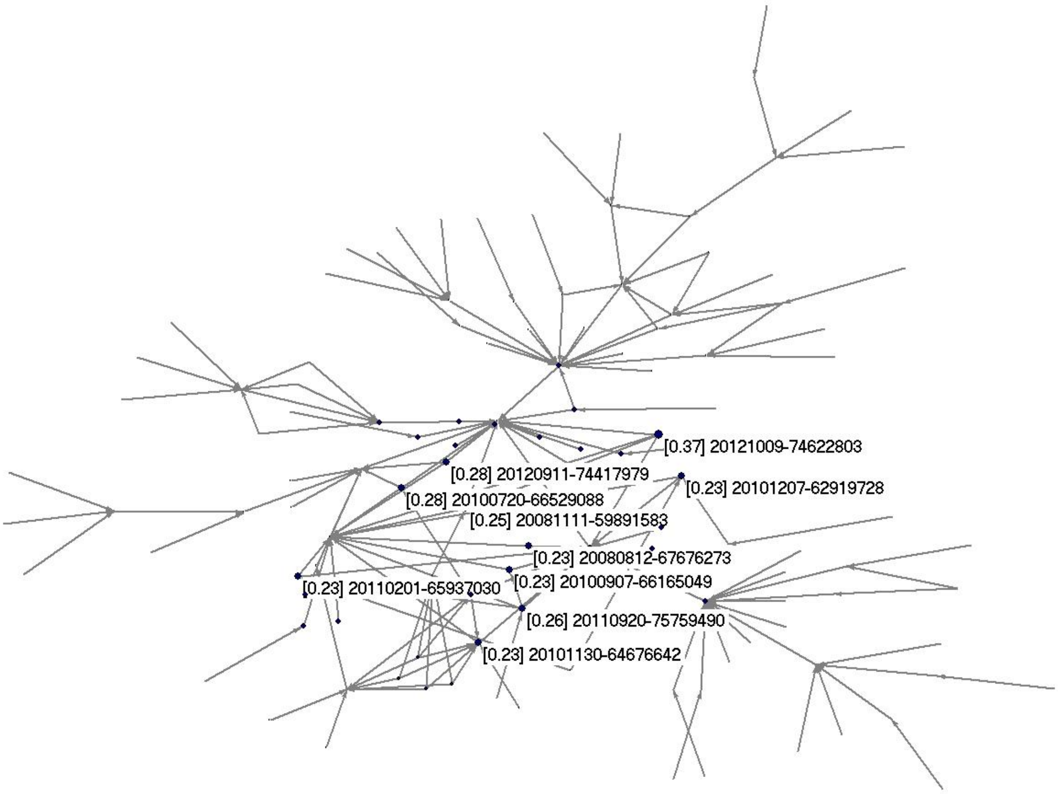

Figure 5.5.NP5. The hub patents of NP5

<u>SPC (Figure 5.6.NP5, Table 5.12.NP5)</u> – It highlights a technological trajectory characterized by the following six patents:

1. P5;
2. patent labelled '20040120-67961951', published in US by the Emcore Corporation with the title 'Apparatus and method for optimizing the efficiency of a bypass diode in multijunction solar cells';
3. patent labelled '20050308-61884858', published as US6864414 (B2) by the Emcore Corporation, with the title 'Apparatus and method for integral bypass diode in solar cells';
4. patent labelled '20100720-66529088', published in US by the Emcore Corporation, with the title 'Apparatus and method for integral bypass diode in solar cells'. This and the previous patent are two different versions of a similar patent;
5. patent labelled '20110614-74510857', published in US by the Emcore Corporation, with the title 'String interconnection and fabrication of inverted metamorphic multijunction solar cells';
6. patent labelled '20120911-72591811', published in 2012, by Emcore Corporation, with the title 'Wafer level interconnection of inverted metamorphic multijunction solar cells';

It can be argued that the technological trajectory of NP5 has been strongly influenced by the American Emcore Corporation with several patents dealing with the solar technology.

Table 5.12.NP5. Vertices on main path SPC [flow] of NP5

Rank	Vertex	Cluster	Id (Label)
1	1 (P5)	1	20001129-00575154
2	3	1	20040120-67961951
3	4	1	20050308-61884858
4	30	1	20100720-66529088
5	56	1	20110614-74510857
6	110	1	20120911-72591811

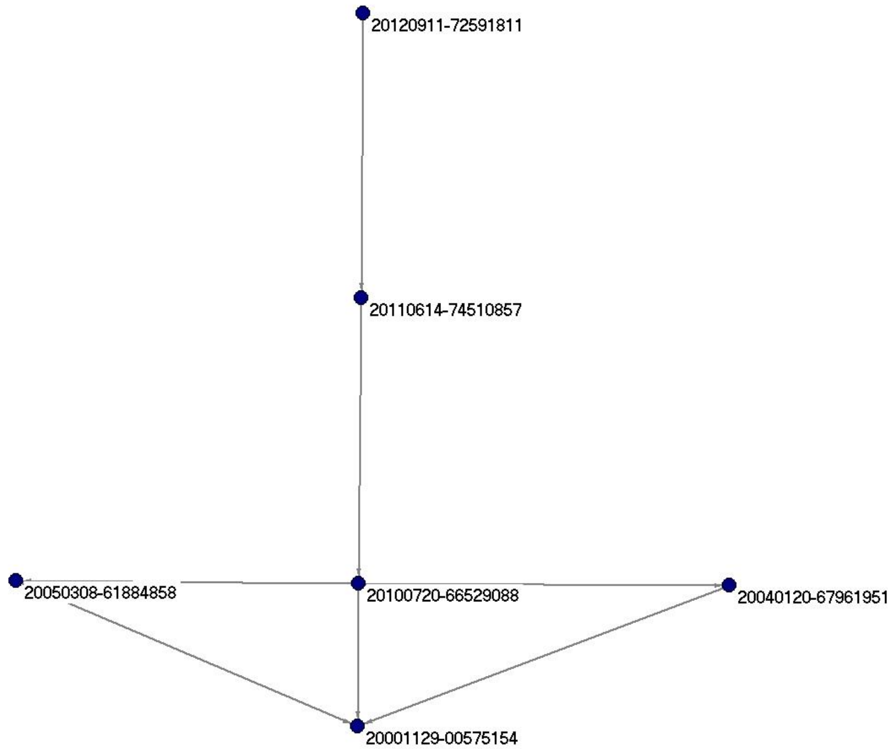

Figure 5.6.NP5. SPC of NP5

Network and connectivity analysis of network built on P6 (NP6) - 20000308-00597537

P6 is the European patent published by the British company English Electric Valve Ltd, which develops and manufactures technology systems and components. The title of P5 is 'Manufacturing method for a solar cell having a protection diode' (IPC: H01L27/142; H01L31/068). NP6 shows the characteristics displayed in Table 5.7.NP6.

Table 5.7.NP6. Characteristics

Number of vertices (n)	**10**
	Arcs
Total number of lines	9
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.09
Average degree	1.80

In-degree centrality (Figure 5.1.NP6; Table 5.8.NP6) – P6 is third in the first four positions with a value of 2. The first most cited patent (vertex 2) was published in Europe by Loral Space System Inc. with the title 'A solar cell assembly', it deals with solar technologies and cosmonautic vehicles using radiation.

Table 5.8.NP6. In-degree and out-degree centrality values of NP6

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	2	3	20010103-21337825	3	1	20040206-23543727
2	4	3	20060316-21466564	10	1	20120830-79184350
3	1 (P6)	2	20000308-00597537	9	1	20120829-76040334
4	3	1	20040206-23543727	8	1	20120621-79218212

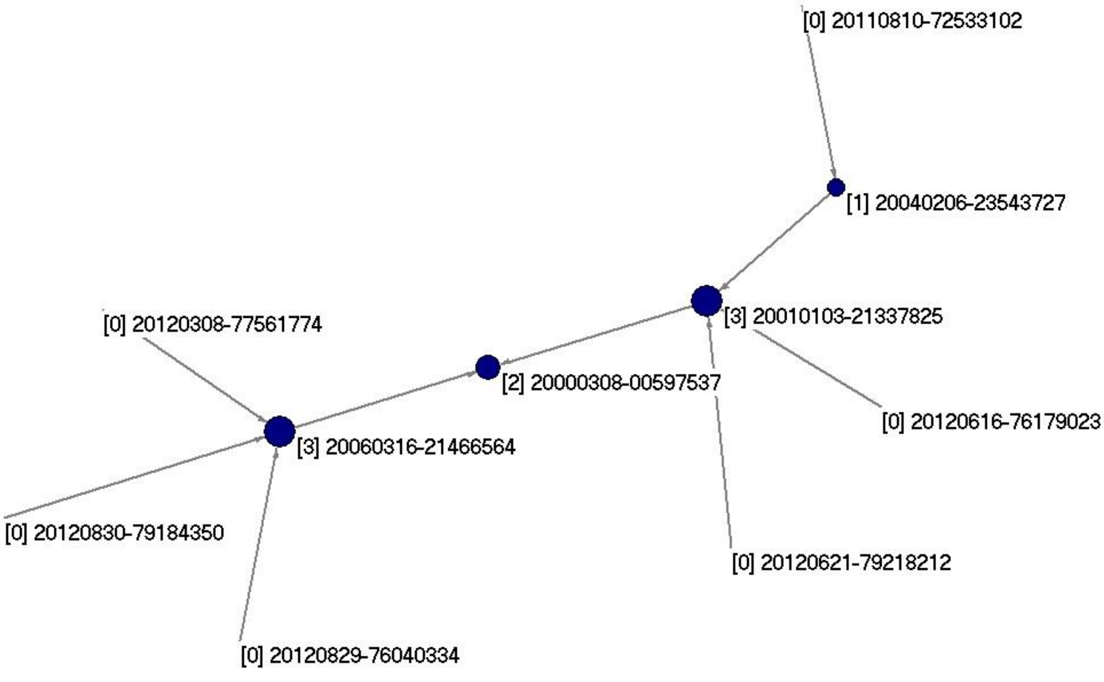

Figure 5.1.NP6. In-degree centrality of NP6

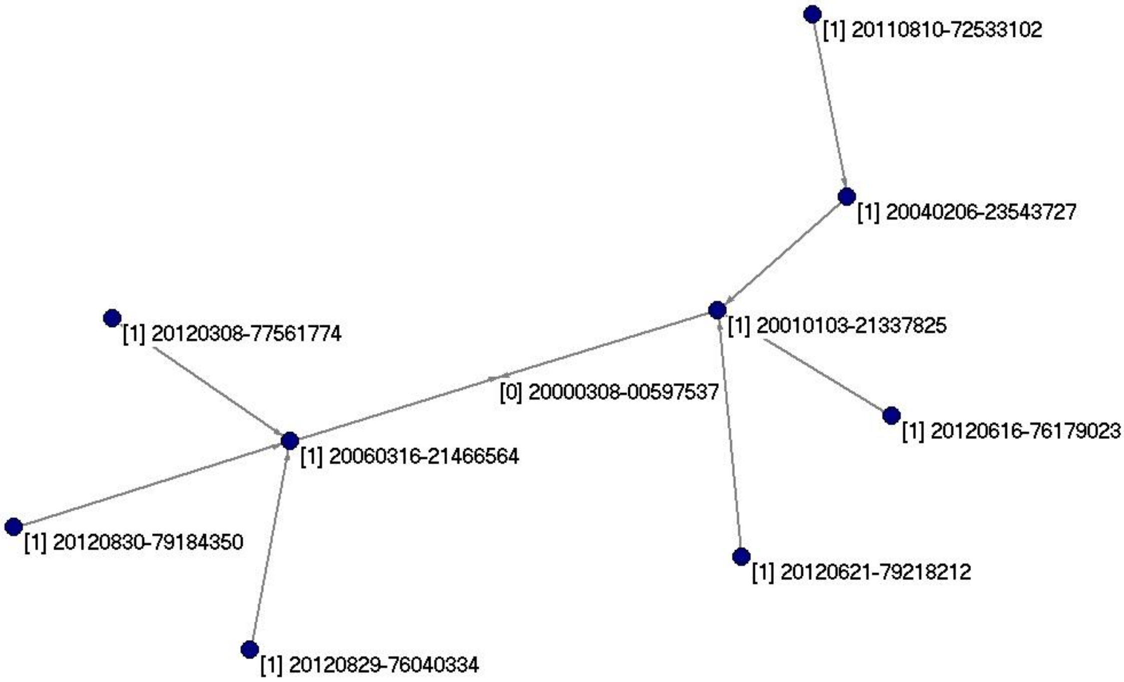

Figure 5.2.NP6. Out-degree centrality of NP6

<u>*Closeness centrality (Figure 5.3.NP6, Table 5.9.NP6)*</u> – P6 is the most connected according to the closeness centrality, with a value of 0.53; the second patent with the same value (vertex 2) was published in Europe by the American company Loral Space Systems, with the title 'A solar cell assembly'. This means that these two patents are near to the centre of local clusters and relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP6, which shows them lying at the centre of the surrounding clusters.

Table 5.9.NP6. Top 10 closeness centrality values of NP6

Rank	Vertex	Value	Id (Label)
1	1 (P6)	0.53	20000308-00597537
2	2	0.53	20010103-21337825
3	4	0.47	20060316-21466564
4	3	0.39	20040206-23543727
5	7	0.36	20120616-76179023
6	8	0.36	20120621-79218212

7	6	0.33	20120308-77561774
8	9	0.33	20120829-76040334
9	10	0.33	20120830-79184350
10	5	0.29	20110810-72533102

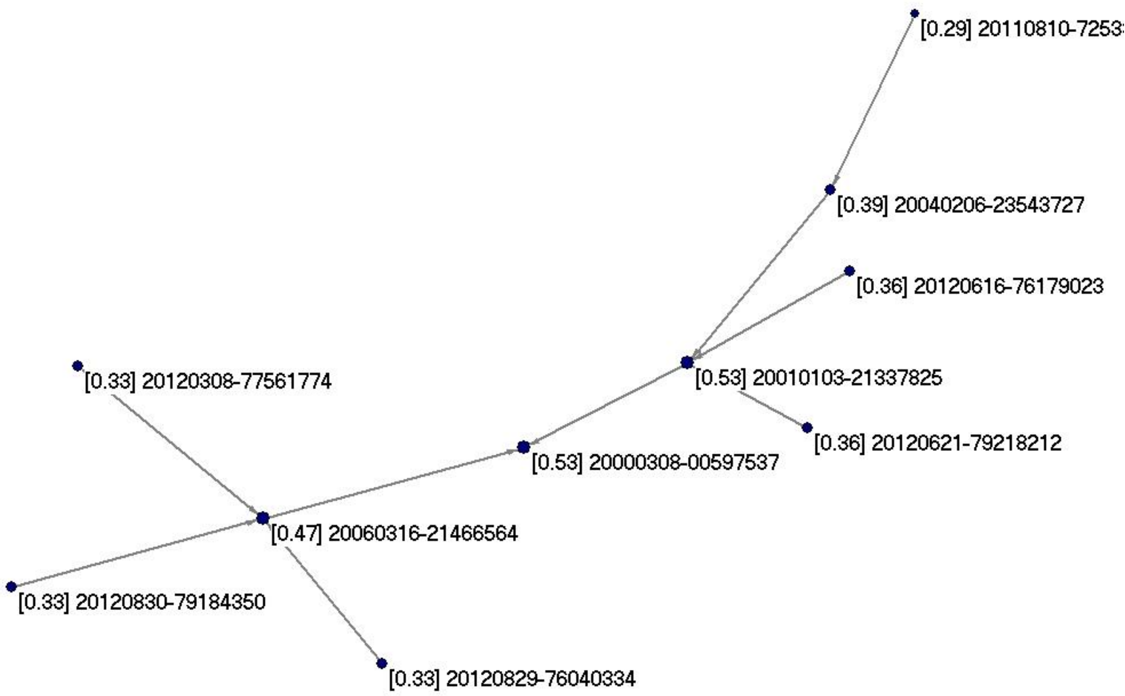

Figure 5.3.NP6. Closeness centrality of NP6

*Authority weights (Figure 5.4.NP6, Table 5.10.NP6)* – The most authority patent is vertex 2, followed by vertex 4 already described as the second most cited, and by P6, with a smaller value (0.02).

Table 5.10.NP6. The authority patents of NP6

Rank	**Vertex**	**Value**	**Id (Label)**
1	2	0.71	20010103-21337825
2	4	0.71	20060316-21466564
3	1 (P6)	0.02	20000308-00597537

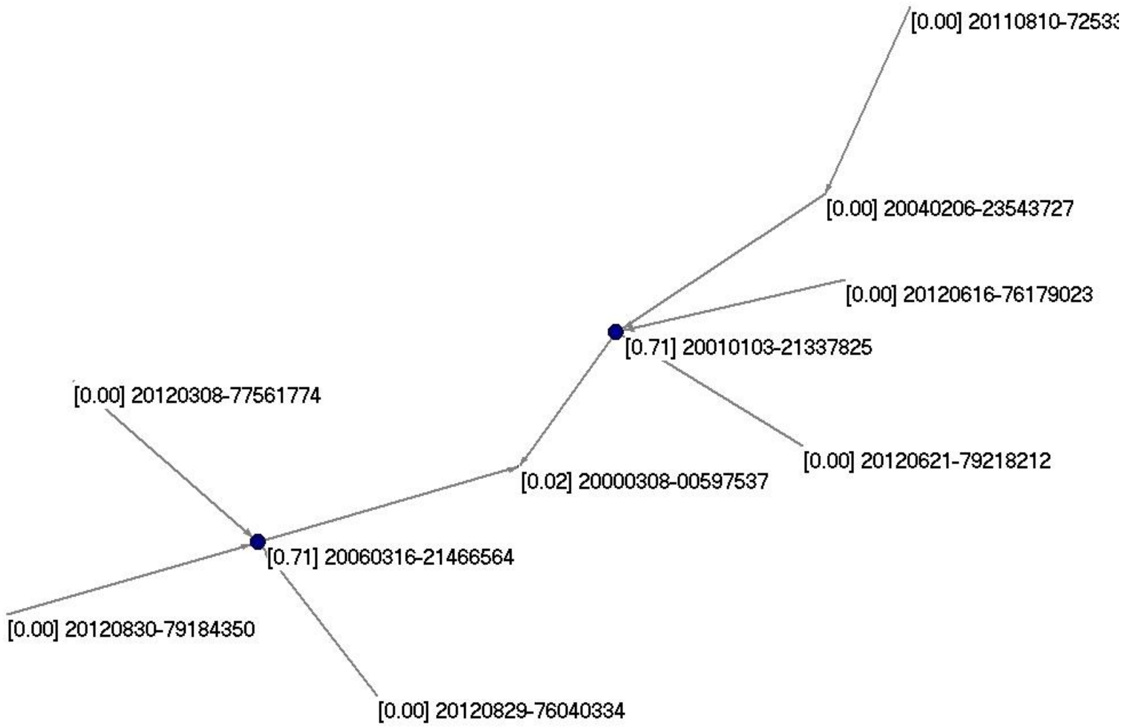

Figure 5.4.NP6. The authority patents of NP6

Hub weights (Figure 5.5.NP6, Table 5.11.NP6) – The best developments of the core inventions previously identified are the eight patents listed in Table 5.11.NP6. The first five, are all equally important:

- vertex 3, published in France by the German Company Astrium GMBH, with the title 'Connector for a solar cell with compensation of movement, uses connector fabricated from metal strip, with central region in the shape of a hollow frame to absorb movement';
- vertex 7, published in Italy by the consortium Dyepower, with the title 'DSSC photovoltaic device comprising photoelectrochemical cells and provided with bypass means and UV filter';
- vertex 6, published simultaneously in several countries by the America company First Solar Inc. with the title 'Photovoltaic module cover';

- vertex 8, published simultaneously in several countries by the Italian consortium Dyepower and four private inventors, with the title ‘DSSC photovoltaic device comprising photoelectrochemical cells and provided with bypass means and UV filter’, it is an alternative version of the previous patent;
- vertex 10, published simultaneously in several countries by the German Soitech Solar GMBH, with the title ‘Solar cell arrays for concentrator photovoltaic modules’.

Table 5.11.NP6. The hub patents of NP6

Rank	Vertex	Value	Id (Label)
1	3	0.41	20040206-23543727
2	7	0.41	20120616-76179023
3	6	0.41	20120308-77561774
4	8	0.41	20120621-79218212
5	10	0.41	20120830-79184350
6	9	0.41	20120829-76040334
7	4	0.01	20060316-21466564
8	2	0.01	20010103-21337825
9	3	0.41	20040206-23543727
10	7	0.41	20120616-76179023

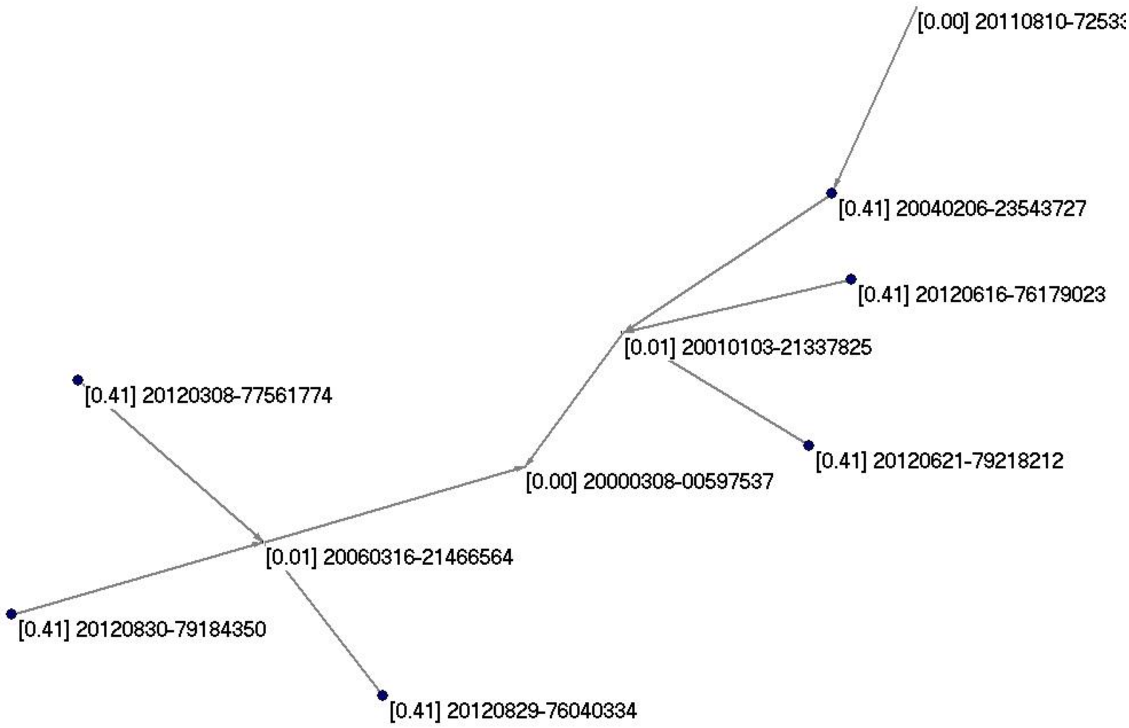

Figure 5.5.NP6 the hub patents of NP6

<u>*SPC (Figure 5.6.NP6, Table 5.12.NP6)*</u> – The 10 patents composing NP6 are all part of the technological trajectory of NP6. This starts from P6, followed by two patents (the first 2 authorities in NP6) from which two different lines depart.

Table 5.12.NP6. Vertices on main path SPC [flow] of NP6

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000308-00597537
2	2	1	20010103-21337825
3	3	1	20040206-23543727
4	4	1	20060316-21466564
5	5	1	20110810-72533102
6	6	1	20120308-77561774
7	7	1	20120616-76179023
8	8	1	20120621-79218212
9	9	1	20120829-76040334
10	10	1	20120830-79184350

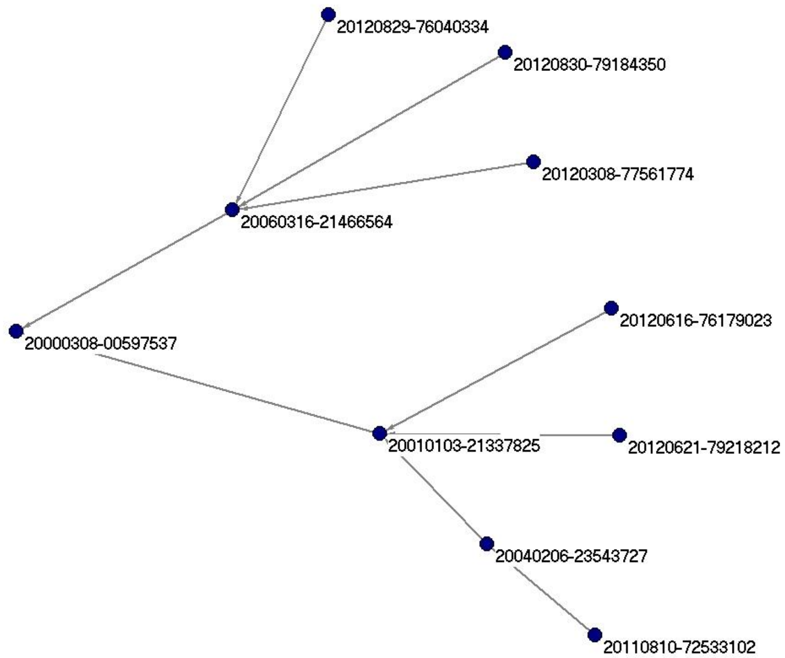

Figure 5.6.NP6. SPC of NP6

Network and connectivity analysis of network built on P10 (NP10)- 20000823-18051117

P10 is the European patent published in 2000 with the title 'Solar cell module and solar cell panel', owned by the Japanese company Sharp KK, a multinational corporation that designs and manufactures electronic products. NP10 characteristics are given in Table 5.7.NP10.

Table 5.7.NP10. Characteristics

Number of vertices (n)	**132**
	Arcs
Total number of lines	176
Number of loops	6
Number of multiple lines	0
Density [loops allowed]	0.01
Average degree	2.66

<u>*In-degree centrality (Figure 5.1.NP10; Table 5.8.NP10)*</u> – P10 occupies fifth position with a value of 9; the first most cited patent (vertex 32), published in the US by PVT Solar, with the title 'Mounting assembly for arrays and other surface-mounted equipment'. It deals with solar technology and thermal insulation.

Table 5.8.NP10. Top 10 in-degree centrality values of NP10

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	32	11	20101228-67686430	23	5	20100722-73856832
2	35	10	20110308-74930119	50	4	20110901-77465610
3	5	9	20051027-68055902	84	4	20120426-79560608
4	11	9	20080902-67017250	17	4	20100225-72682175
5	1 (P10)	9	20000823-18051117	122	3	20121127-74526939
6	26	7	20100930-74621952	118	3	20120925-79443841
7	17	7	20100225-72682175	110	3	20120821-79037954
8	34	7	20110308-66353083	106	3	20120802-80362911
9	69	7	20120228-79192412	103	3	20120724-79036388
10	23	6	20100722-73856832	80	3	20120412-80286816

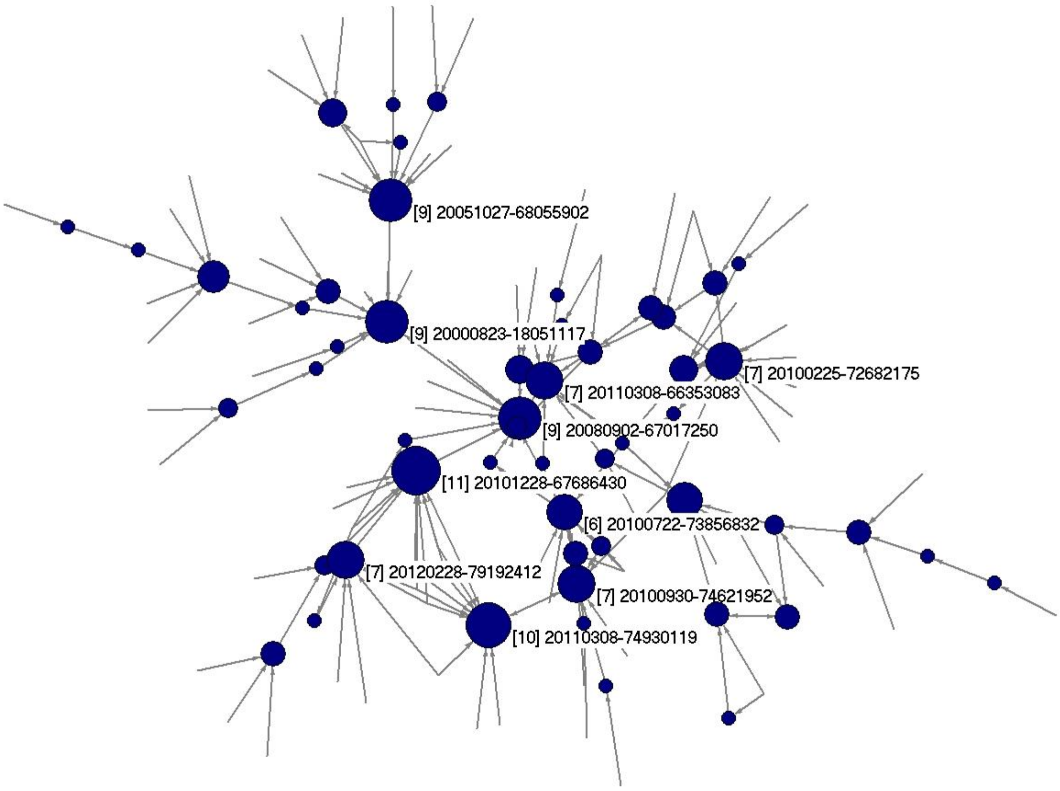

Figure 5.1.NP10. In-degree centrality of NP10

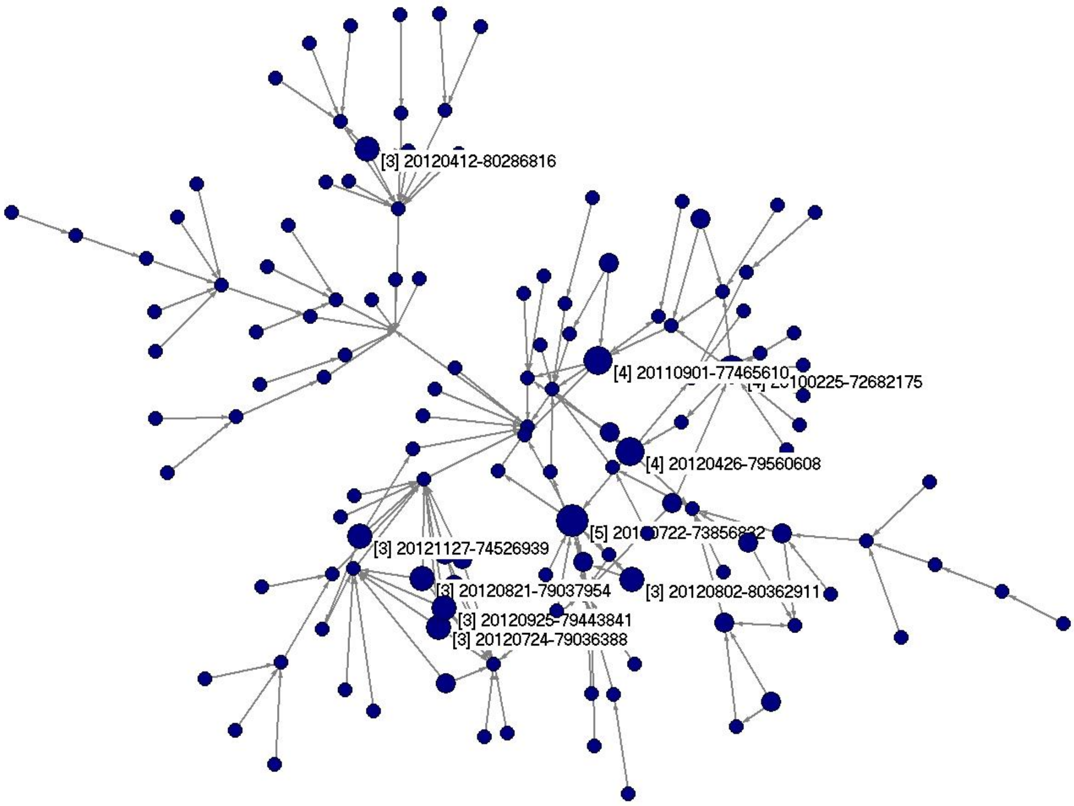

Figure 5.2.NP10. Out-degree centrality of NP10

<u>Closeness centrality (Figure 5.3.NP10; Table 5.9.NP10)</u> – According to the closeness centrality measure, P10 occupies fourth position (value = 0.2) in the top ten patents. The first most cited patent (vertex 11) was published in the US by the American company Solaria Corporation and with the title 'Electrical coupling device and method for solar cells'. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP10, which shows vertex 11 lying at the centre of the surrounding clusters.

Table 5.9.NP10. Top 10 closeness centrality values of NP10

Rank	**Vertex**	**Value**	**Id (Label)**
1	11	0.31	20080902-67017250
2	34	0.29	20110308-66353083
3	113	0.27	20120904-77102430
4	1 (P10)	0.27	20000823-18051117

5	31	0.27	20101228-62359163
6	84	0.27	20120426-79560608
7	108	0.26	20120807-75640449
8	23	0.26	20100722-73856832
9	32	0.26	20101228-67686430
10	50	0.25	20110901-77465610

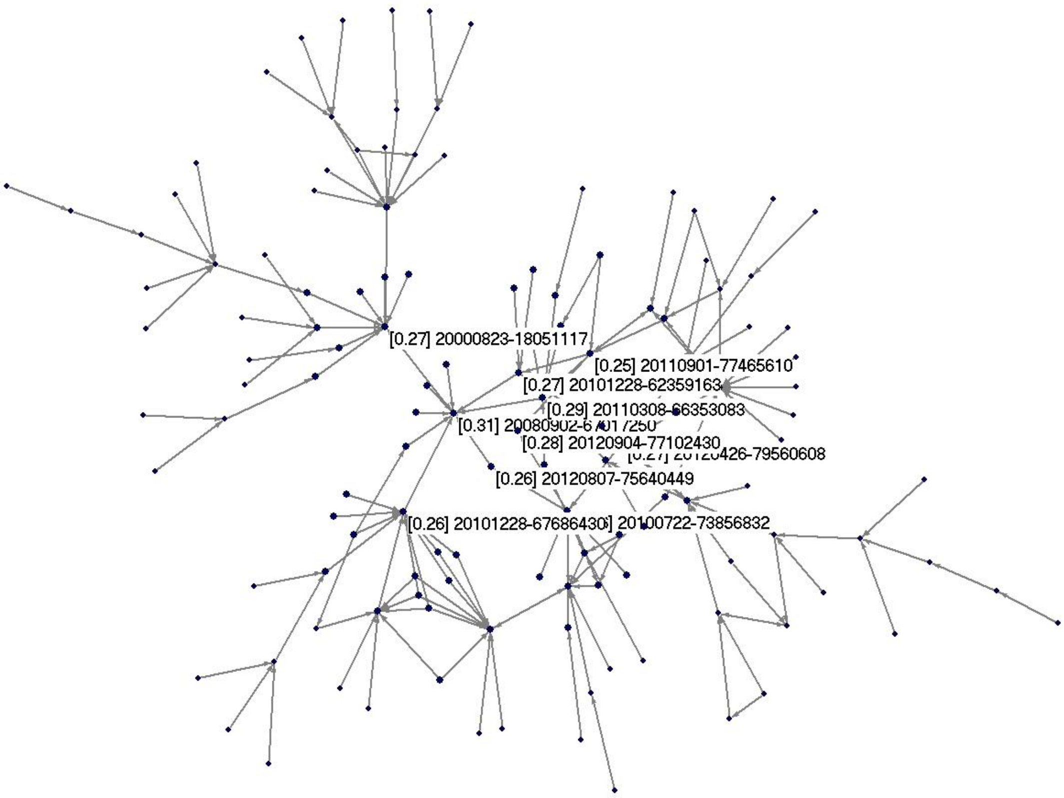

Figure 5.3.NP10. Closeness centrality of NP10

<u>*Authority weights (Figure 5.4.NP10; Table 5.10.NP10)*</u> – P10 does not appear in the top 10 patents, it is ranked 19th with a value equal to 0.0032. We only include values to the first two decimal places, therefore, in Table 5.10.NP10 we keep only the first eight authority patents. They are:

- vertex 32, which is also the most cited (1st in-degree centrality value);
- vertex 35, published in the US by the company IB Roof Systems, with the title ‘Method of securing flexible solar panel to PVC roofing membrane’;

- vertex 69, published in the US by a private inventor with the title 'Roof mounting system';
- vertex 23, published in the US, by the American Certain Teed Corporation, with the title 'Photovoltaic roof covering';
- vertex 88, published in the US by the company PVT Solar, with the title 'Mounting assembly for arrays and other surface-mounted equipment'.

Table 5.8.NP10. The authority patents of NP10

Rank	Vertex	Value	Id (Label)
1	32	0.66	20101228-67686430
2	35	0.64	20110308-74930119
3	69	0.39	20120228-79192412
4	23	0.06	20100722-73856832
5	88	0.04	20120515-77101912
6	67	0.02	20120202-79038083
7	34	0.02	20110308-66353083
8	22	0.02	20100715-73802391

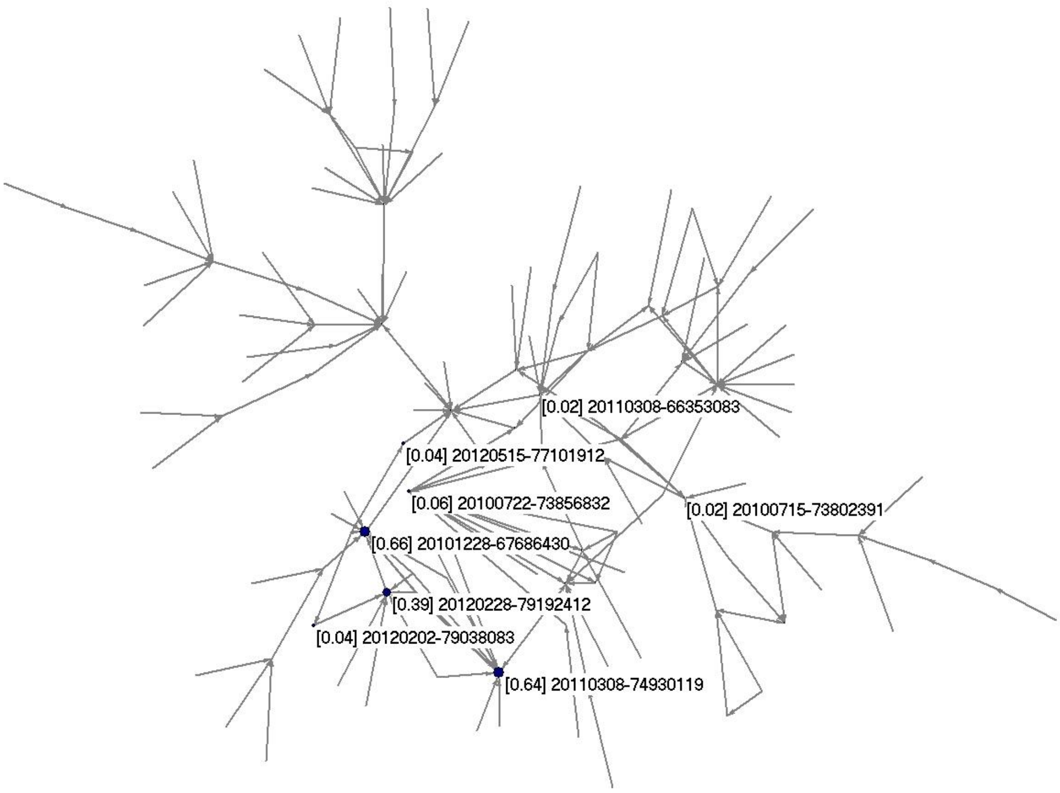

Figure 5.4.NP10. The authority patents of NP10

<u>*Hub weights (Figure 5.5.NP10; Table 5.11.NP10)*</u> – In the best developments of the core inventions previously identified, one company with similar patents published in several versions. The first five positions are occupied by patents published mainly by the Vermont Slate & Copper Services Inc.:

- vertex 118, published in the US and entitled 'Roofing grommet forming a seal between a roof-mounted structure and a roof';
- vertex 110, published in the US and is an alternative version of the previous patent;
- vertex 103, published in the US 'Roofing system and method';
- vertex 90, published in the US by private inventors with the title 'Roofing system and method';
- vertex 87, published in the US by private inventors with the title 'Roofing system and method'.

Table 5.11.NP10. Top 10 hub patents of NP10

Rank	**Vertex**	**Value**	**Id (Label)**
1	118	0.39	20120925-79443841
2	110	0.39	20120821-79037954
3	103	0.39	20120724-79036388
4	90	0.30	20120522-79038055
5	87	0.30	20120501-79038106
6	79	0.30	20120410-77821787
7	98	0.24	20120703-76742684
8	122	0.17	20121127-74526939
9	26	0.16	20100930-74621952
10	49	0.15	20110811-77239562

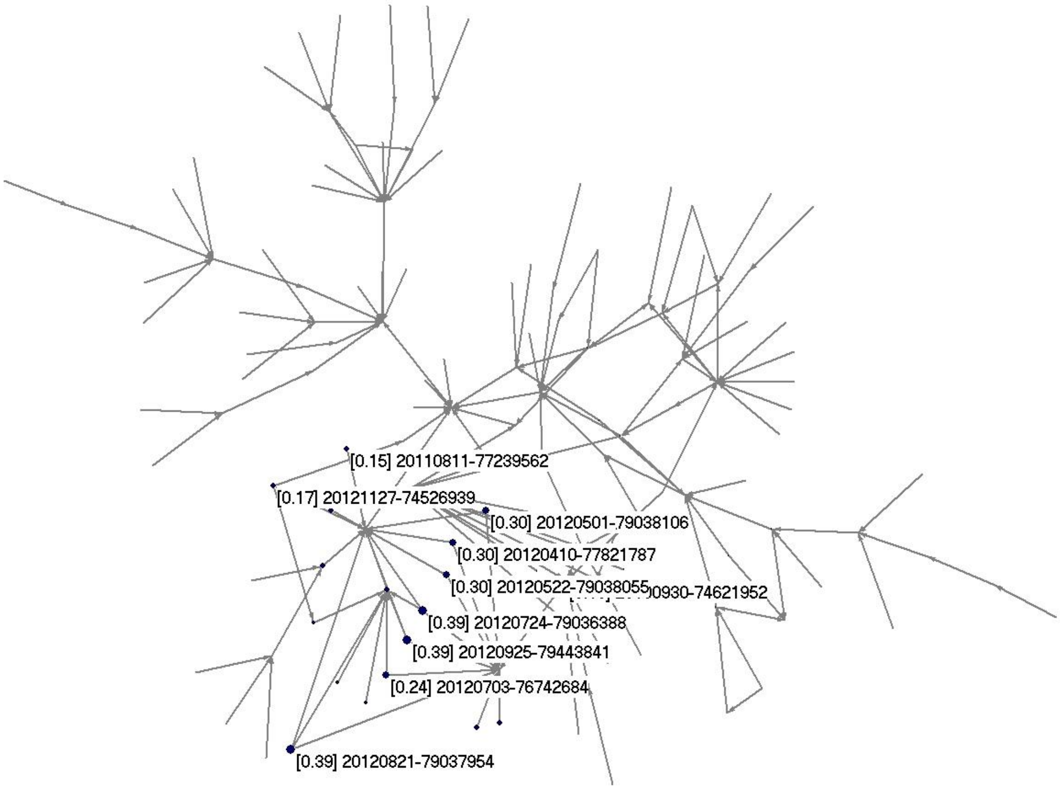

Figure 5.5.NP10. The hub patents of NP10

<u>*SPC (Figure 5.6.NP10, Table 5.12.NP10)*</u> – NP10 has four strong components, which we shrank to apply the SPC. The SPC result includes 104 of the 132 patents, as shown in Figure 5.6.NP10.

Table 5.12.NP10. Vertices on main path SPC [flow] of NP10

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000823-18051117
2	2	1	20030612-01704253
3	3	1	20040730-23526077
4	4	1	20040902-25975338
5	5	1	20051027-68055902
6	6	1	20080306-68235732
7	7	1	20080529-68287804
8	8	1	20080612-68246394
9	9	1	20080807-00065539
10	10	1	20080814-17239194
11	11	1	20080902-67017250
12	12	1	20090423-70046679
13	13	1	20091001-70266212

14	14	1	20091001-71484850
15	16	1	20091210-72077683
16	15	1	20100107-72318789
17	18	1	20100415-73640456
18	19	1	20100527-71971196
19	21	1	20100701-73717998
20	22	1	20100715-73802391
21	23	1	20100722-73856832
22	24	1	20100908-70045119
23	27	1	20101021-74905460
24	29	1	20101116-75071282
25	30	1	20101118-75075995
26	31	1	20101228-62359163
27	32	1	20101228-67686430
28	33	1	20110113-75423543
29	34	1	20110308-66353083
30	36	1	20110324-76202018
31	37	1	20110414-76379283
32	39	1	20110428-76454903
33	40	1	20110505-76502650
34	41	1	20110609-76779318
35	42	1	20110616-76866646
36	43	1	20110616-76868845
37	44	1	20110630-77170098
38	45	1	20110706-72676033
39	46	1	20110707-77004895
40	47	1	20110721-77173450
41	48	1	20110726-77474377
42	49	1	20110811-77239562
43	52	1	20110929-77632730
44	53	1	20111006-77709294
45	54	1	20111006-77710187
46	55	1	20111027-77929028
47	56	1	20111103-78038101
48	57	1	20111103-78041250
49	58	1	20111114-75321292
50	59	1	20111117-78137992
51	61	1	20111221-78949995
52	62	1	20111222-78711342
53	63	1	20111229-78750185
54	64	1	20120117-67868918
55	65	1	20120117-75287726
56	66	1	20120202-79026213
57	67	1	20120202-79038083
58	69	1	20120228-79192412
59	70	1	20120301-79199318

60	71	1	20120301-79206095
61	74	1	20120313-73081160
62	75	1	20120329-79403836
63	76	1	20120329-79407826
64	79	1	20120410-77821787
65	80	1	20120412-80286816
66	82	1	20120424-75934054
67	83	1	20120426-77905977
68	85	1	20120426-79561668
69	86	1	20120501-75971719
70	87	1	20120501-79038106
71	88	1	20120515-77101912
72	90	1	20120522-79038055
73	91	1	20120530-78460591
74	93	1	20120607-79865819
75	94	1	20120614-78446126
76	95	1	20120614-79906810
77	97	1	20120626-76379281
78	98	1	20120703-76742684
79	99	1	20120705-80098829
80	100	1	20120710-78814954
81	101	1	20120711-78885461
82	102	1	20120712-80192972
83	103	1	20120724-79036388
84	106	1	20120802-80362911
85	108	1	20120807-75640449
86	109	1	20120821-74929537
87	110	1	20120821-79037954
88	111	1	20120828-75057530
89	112	1	20120830-80448932
90	113	1	20120904-77102430
91	114	1	20120906-80620389
92	115	1	20120907-79184359
93	116	1	20120920-80742653
94	118	1	20120925-79443841
95	119	1	20121001-76600346
96	120	1	20121031-80990903
97	122	1	20121127-74526939
98	124	1	20121206-79785645
99	125	1	20121206-81221598
100	126	1	20121220-81480129
101	127	1	20130101-67110407
102	128	1	20130101-73564677
103	129	1	20130108-77275749
104	131	1	20130110-79910788
105	132	1	20130116-77076007

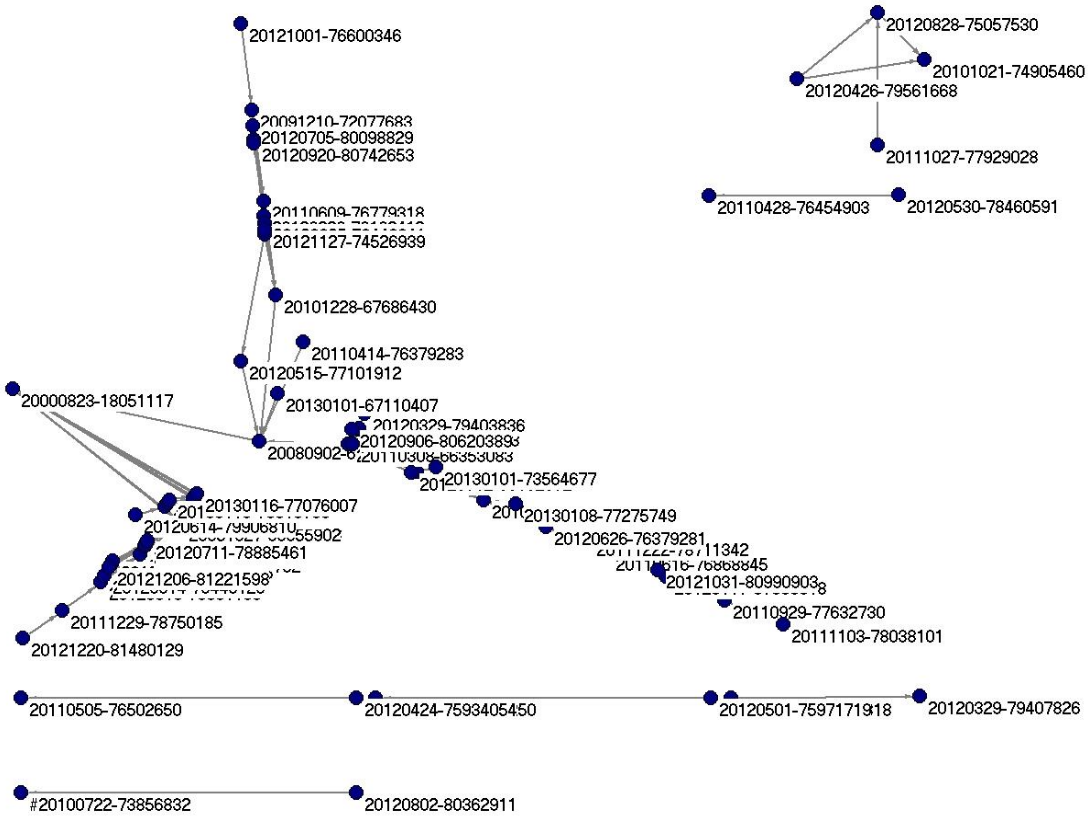

Figure 5.6.NP10. SPC of NP10

Network and connectivity analysis of network built on P11 (NP11)- 20000830-18052547

P11 was published in 2000 in Europe by the Japanese company Canon KK, entitled 'Installation structure of solar cell module array, installation method of solar cell module, and sunlight power generation system' (IPC:E04D13/18; H01L31/042). NP11 characteristics are given in Table 5.7.NP11.

Table 5.7.NP11. Characteristics

Number of vertices (n)	**162**
	Arcs
Total number of lines	189
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.00
Average degree	2.33

In-degree centrality (Figure 5.1.NP11, Table 5.8.NP11) – P11 does not appear in the top 10 list, it obtains an in-degree value equal to 3 and is 12th in the ranking. The first most cited patent is vertex 7, published in the US by four private inventors with the title 'Distributed power harvesting system using DC power sources'. It deals with electricity and circuit arrangements for ac mains or ac distribution networks.

Table 5.8.NP11. Top 10 in-degree and out-degree centrality values of NP11

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	7	48	20080619-67701485	142	4	20120925-79672741
2	17	17	20100708-73776878	7	2	20080619-67701485
3	6	16	20070719-64966255	124	2	20120724-74176626
4	8	7	20090728-66063768	122	2	20120710-78814954
5	28	6	20101209-75398156	120	2	20120703-76504268
6	39	6	20110308-67701227	118	2	20120621-78460147
7	75	6	20111115-74198273	54	2	20110802-71913017
8	3	5	20050426-60728524	103	2	20120329-79405190
9	80	4	20120103-74320098	101	2	20120320-76211801
10	9	4	20091103-67922748	100	2	20120320-71912771

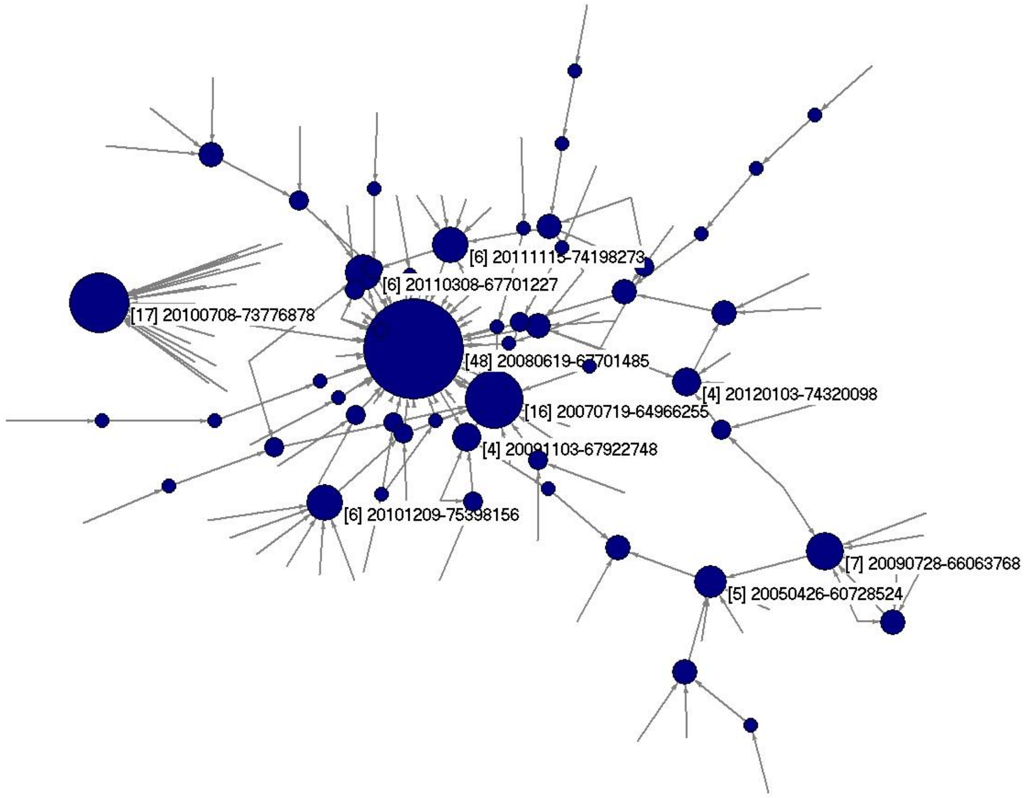

Figure 5.1.NP11. In-degree centrality of NP11

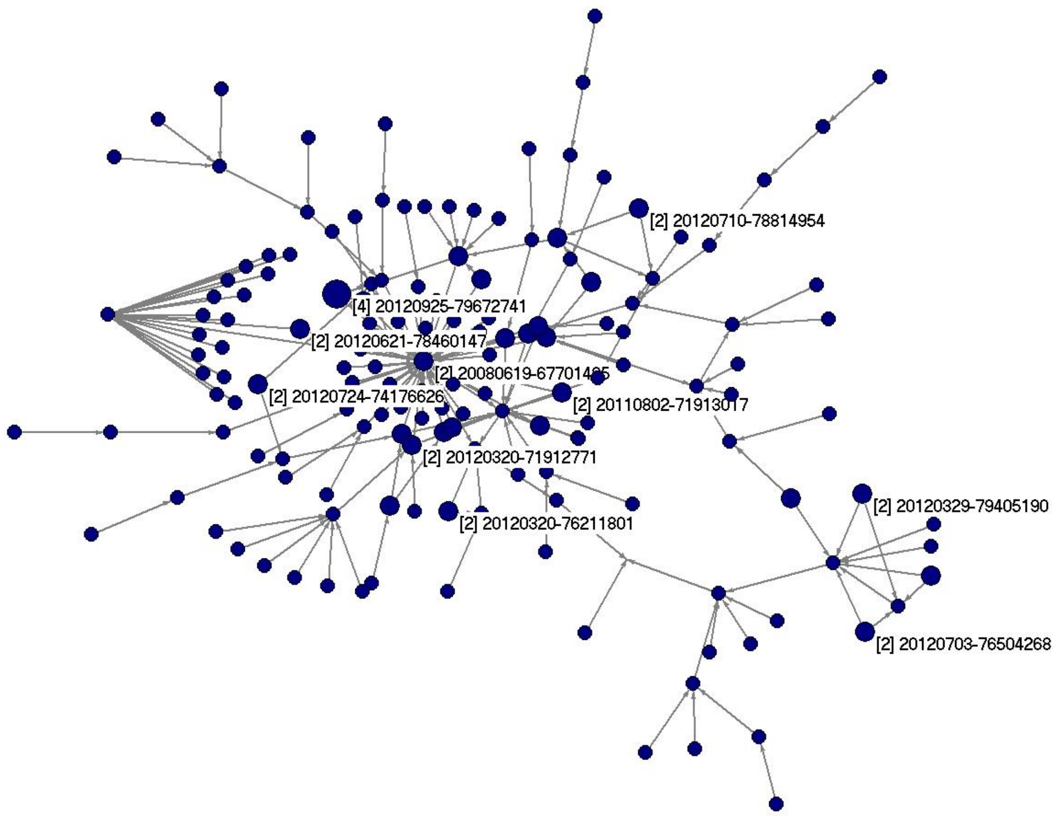

Figure 5.2.NP11. Out-degree centrality of NP11

<u>*Closeness centrality (Figure 5.3.NP11, Table 5.9.NP11)*</u> – P11 obtains a closeness centrality value equal to 0.21, it does not appear in the first 10 and is ranked 106th. Closeness centrality values confirm the role of vertex 7 (1st in-degree centrality). This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP11, which shows this patent lying at the centre of the surrounding clusters.

Table 5.9.NP11. Top 10 closeness centrality measures of NP11

Rank	**Vertex**	**Value**	**Id (Label)**
1	7	0.41	20080619-67701485
2	6	0.33	20070719-64966255
3	9	0.32	20091103-67922748
4	20	0.31	20100930-74624927
5	17	0.30	20100708-73776878
6	42	0.30	20110614-76837030
7	100	0.30	20120320-71912771
8	75	0.30	20111115-74198273
9	39	0.30	20110308-67701227
10	47	0.30	20110628-71913033

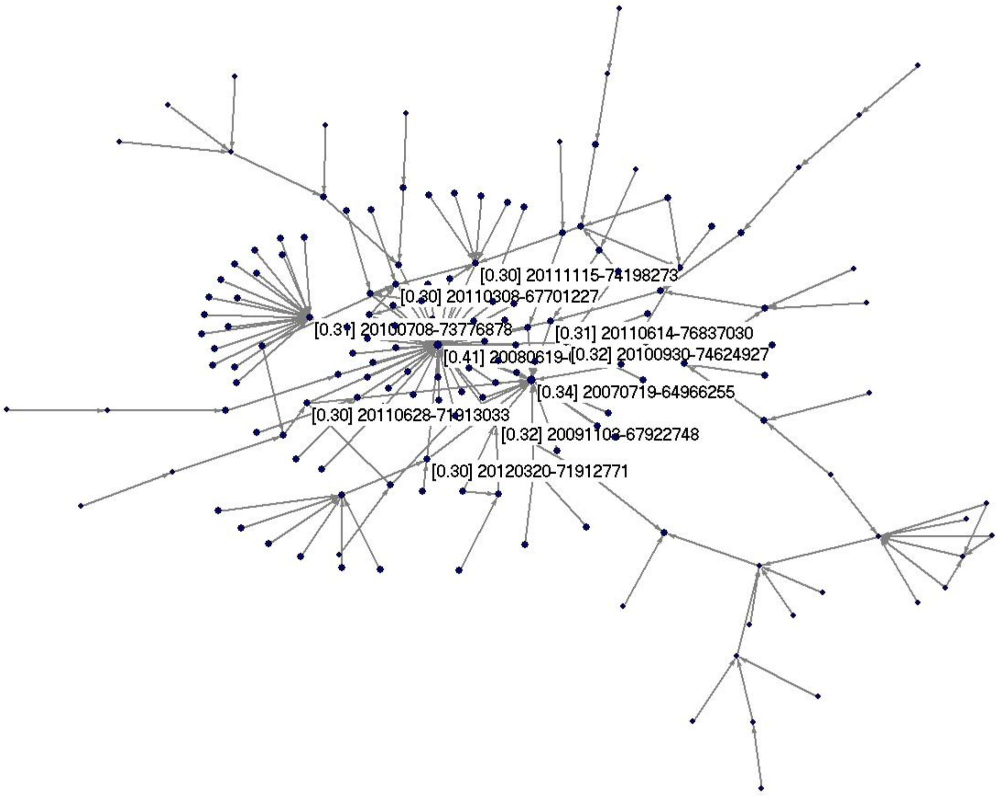

Figure 5.3.NP11. Closeness centrality of NP11

<u>*Authority weights (Figure 5.4.NP11, Table 5.10.NP11)*</u> – P11 is not an authority patent; its weight is zero. The first five most authority patents are:

- vertex 7, which is the most cited patent in NP11;
- vertex 6, published in the US by company Koninkijke Phillips Electronics, with the title 'Decentralized power generation system';
- vertex 38, published in the US by Solaredge Ltd, with the title 'Current bypass for distributed power harvesting systems using DC power sources';
- vertex 17, published simultaneously in different countries by the company Anometrics, with the title 'Electrical safety shutoff system and devices for photovoltaic modules';

- vertex 84, published in the US by the company Tigo Energy Inc., with the title 'Device for distributed maximum power tracking for solar arrays'.

Table 5.10.NP11. The authority patents of NP11

Rank	Vertex	Value	Id (Label)
1	7	0.96	20080619-67701485
2	6	0.25	20070719-64966255
3	38	0.09	20110308-67701227
4	17	0.03	20100708-73776878
5	84	0.02	20120110-76162101
6	75	0.02	20111115-74198273
7	88	0.02	20120124-75815367
8	80	0.02	20120103-74320098

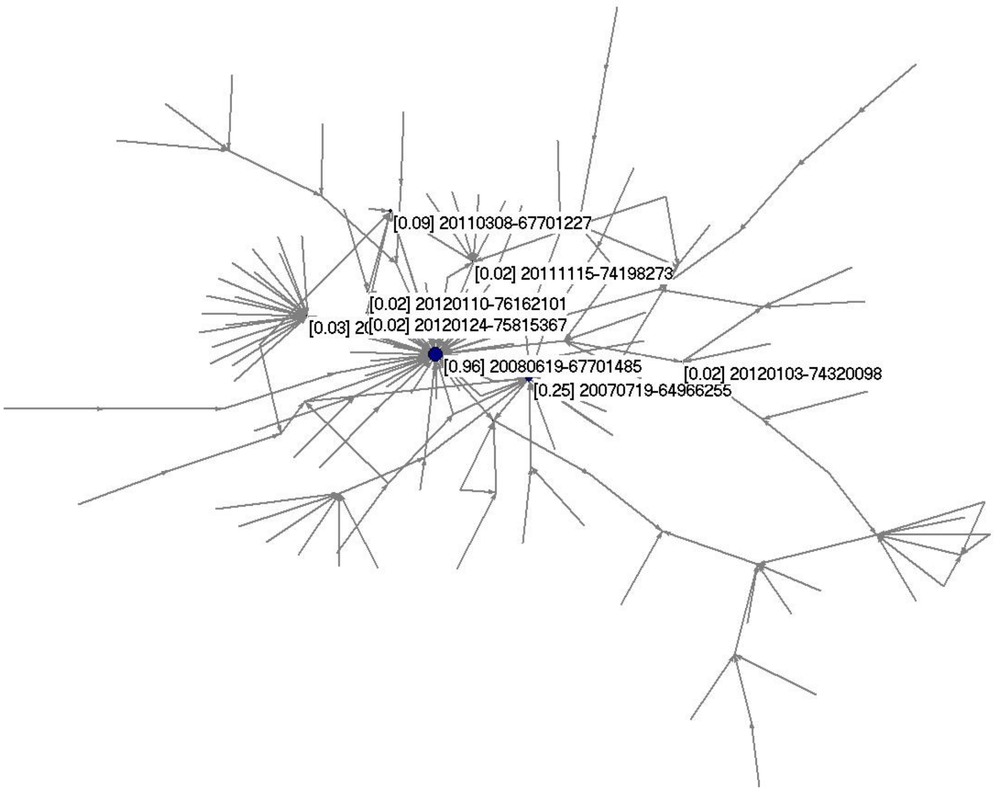

Figure 5.4.NP11. The authority patents of NP11

<u>*Hub weights (Figure 5.5.NP11, Table 5.11.NP11*</u>) – The first five hubs identified among the top 10 list, have the same value of 0.17:

- vertex 54, published in the US by the National Semiconductor Corporation, with the title ‘Method and system for selecting between centralized and distributed maximum power point tracking in an energy generating system’;
- vertex 100, published in the US, and owned by the Nat Semiconductor Corporation, with the title ‘System and method for integrating local maximum power point tracking into an energy generating system having centralized maximum power point tracking’;
- vertex 47, published in the US by the Nat Semiconductor Corporation, with the title ‘Method and system for providing local converters to provide maximum power point tracking in an energy generating system’;
- vertex 87, published in the US by Tigo Energy Inc., with the title ‘Step-up converter systems and methods’;
- vertex 42, published in the US, by the Nat Semiconductor Corporation with the title ‘Method and system for providing central control in an energy generating system’.

Table 5.11.NP11. Top 10 hub weights of NP11

Rank	Vertex	Value	Id (Label)
1	54	0.17	20110802-71913017
2	100	0.17	20120320-71912771
3	47	0.17	20110628-71913033
4	87	0.17	20120117-72524087
5	42	0.17	20110614-76837030
6	74	0.17	20111115-72522286
7	147	0.17	20121023-70532599
8	145	0.17	20121016-80957689
9	143	0.17	20121002-71914214
10	142	0.15	20120925-79672741

Figure 5.5.NP11. The hub patents of NP11

<u>*SPC (Figure 5.6.NP11, Table 5.12.NP11)*</u> – The technological trajectory of NP11 comprises nine patents. This goes from P11 to the most recent patent '20120503-79595562' published in the US by the company Canada FVD, with the title 'System and method for combining electrical power from photovoltaic sources'.

Table 5.12.NP11. Vertices on main path SPC [flow] of NP11

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000830-18052547
2	6	1	20070719-64966255
3	2	1	20021204-18430408
4	9	1	20091103-67922748
5	7	1	20080619-67701485
6	47	1	20110628-71913033
7	108	1	20120503-79595562
8	143	1	20121002-71914214
9	144	1	20121011-80931269

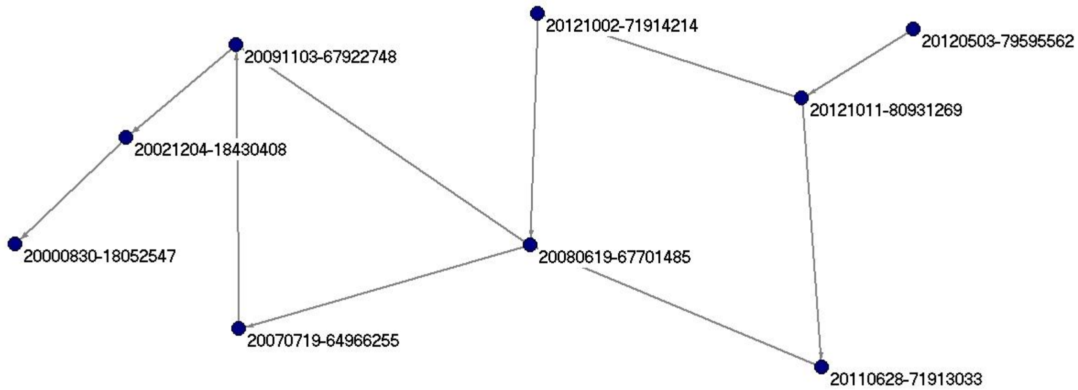

Figure 5.6.NP11. SPC of NP11

Network and connectivity analysis of network built on P12 (NP12) - 20000906-18053580

P12 is a European patent, published in 2000 by two German private inventors. The title is 'Solar collector made of fibres' (IPC: H01L31/0352; H01L31/0384). The characteristics of NP12 are presented in Table 5.7.NP12.

Table 5.7.NP12. Characteristics

Number of vertices (n)	**294**
	Arcs
Total number of lines	353
Number of loops	5
Number of multiple lines	0
Density [loops allowed]	0.00
Average degree	2.4

In-degree centrality (Figure 5.1.NP12, Table 5.8.NP12) – P12 does not appear within the top 10 most cited patents. The first most cited is vertex 5 published in the US by the American Konarca Technologies, with the title 'Low temperature interconnection of nanoparticles'.

Table 5.8.NP12. Top 10 in-degree and out-degree centrality values of NP12

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	5	24	20050222-62617532	279	7	20121218-76502749

2	7	21	20050705-62630664	26	4	20080129-60810759
3	3	16	20030807-57945243	86	4	20100722-73856832
4	39	15	20081111-66786685	170	4	20111206-65115576
5	11	14	20060913-26635294	242	3	20120802-80362911
6	15	13	20070118-49801086	57	3	20091001-71778144
7	56	12	20090924-71430869	53	3	20090811-67717404
8	73	12	20050802-62624826	107	3	20110104-69945392
9	8	12	20100209-64510499	10	3	20060822-67506817
10	6	11	20050531-62617512	158	3	20111010-73933679

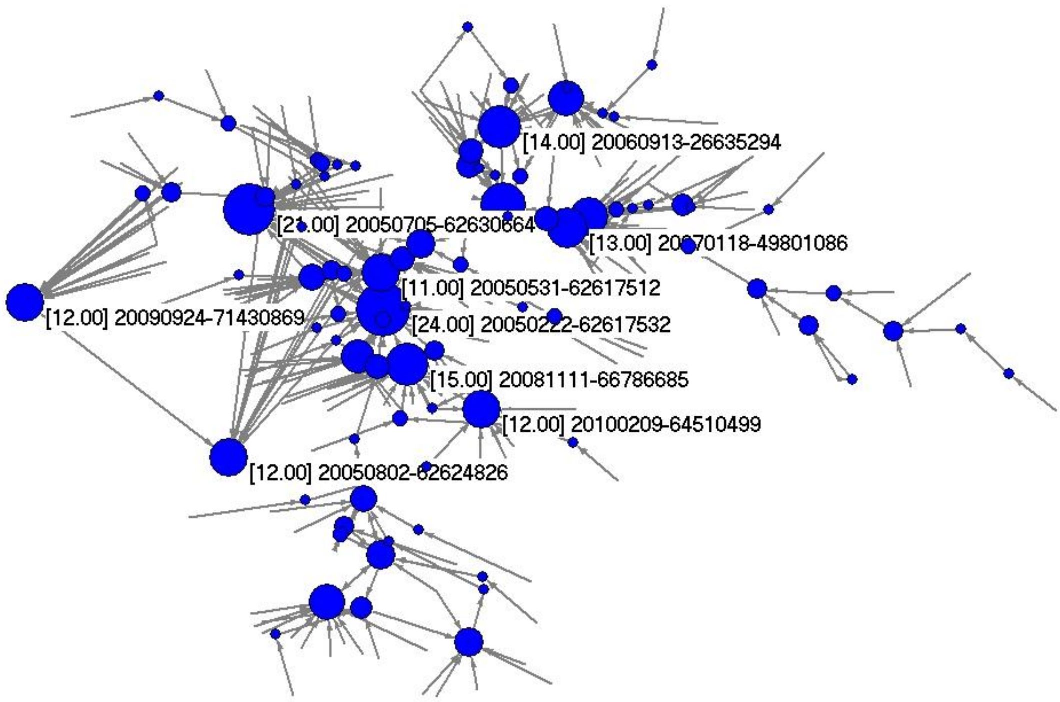

Figure 5.1.NP12. In-degree centrality of NP12

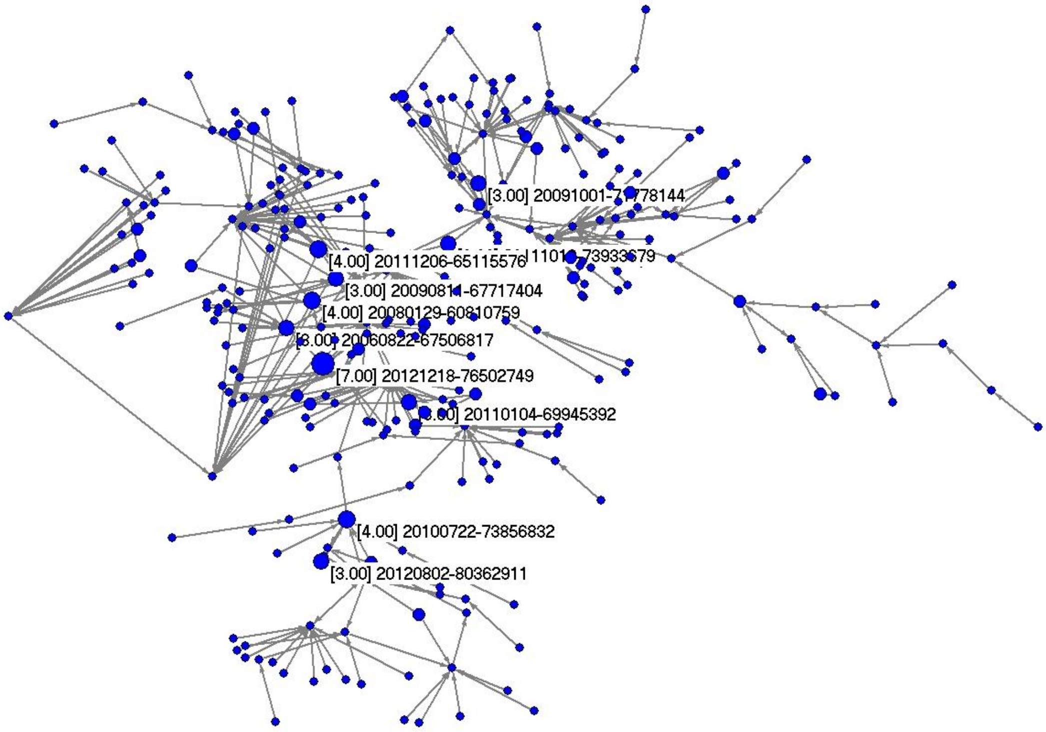

Figure 5.2.NP12. Out-degree centrality of NP12

<u>Closeness centrality (Figure 5.3.NP12, Table 5.9.NP12)</u> – P12 is the first among the top 10 patents according to the closeness centrality values. This means that it is close to the centre of NP12. The top ten patents show very similar values, meaning that they are all relatively close to the centre as shown by Figure 5.3.NP12.

Table 5.9.NP12. Top 10 closeness centrality values of NP12

Rank	Vertex	Value	Id (Label)
1	1 (P12)	0.29	20000906-18053580
2	5	0.27	20050222-62617532
3	3	0.26	20030807-57945243
4	158	0.24	20111010-73933679
5	7	0.24	20050705-62630664
6	26	0.24	20080129-60810759
7	170	0.24	20111206-65115576
8	8	0.23	20050802-62624826
9	10	0.23	20060822-67506817
10	279	02.3	20121218-76502749

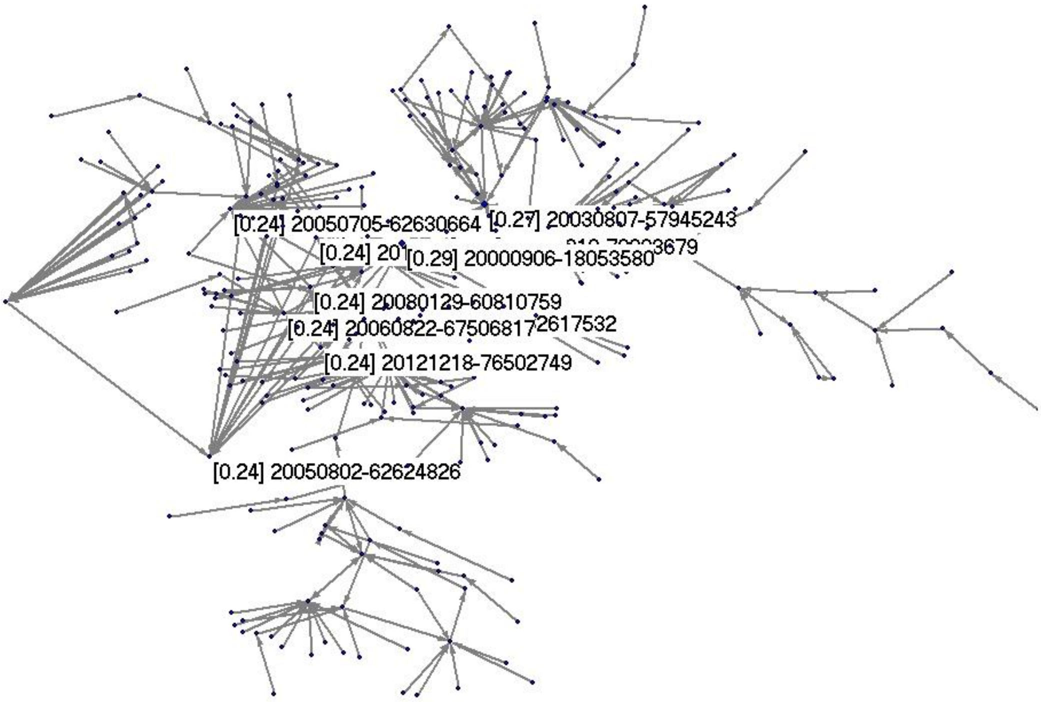

Figure 5.3.NP12. Closeness centrality of NP12

<u>*Authority weights (Figure 5.4.NP12, Table 5.10.NP12)*</u> – The most authority patent - patent vertex 5 - has been described already among the most cited according to in-degree centrality. The other four are:

- vertex 7, published in the US by the American Konarka Technologies, with the title 'Photovoltaic fibers';
- vertex 6, published in the US by the American Konarka Technologies, with the title 'Gel electrolytes for dye sensitized solar cells ';
- vertex 8, published in the US by the American Konarka Technologies, with the title 'Wire interconnects for fabricated interconnected photovoltaic cells';
- vertex 10, published in US by the American Konarka Technologies, with the title 'Low temperature interconnection of nanoparticles'.

Table 5.8.NP12. Top 10 authority patents of NP12

Rank	Vertex	Value	Id (Label)

1	5	0.73	20050222-62617532
2	7	0.53	20050705-62630664
3	6	0.33	20050531-62617512
4	8	0.23	20050802-62624826
5	10	0.06	20060822-67506817
6	26	0.05	20080129-60810759
7	39	0.05	20081111-66786685
8	21	0.05	20070417-62615372
9	19	0.05	20070306-62624190
10	73	0.04	20100209-64510499

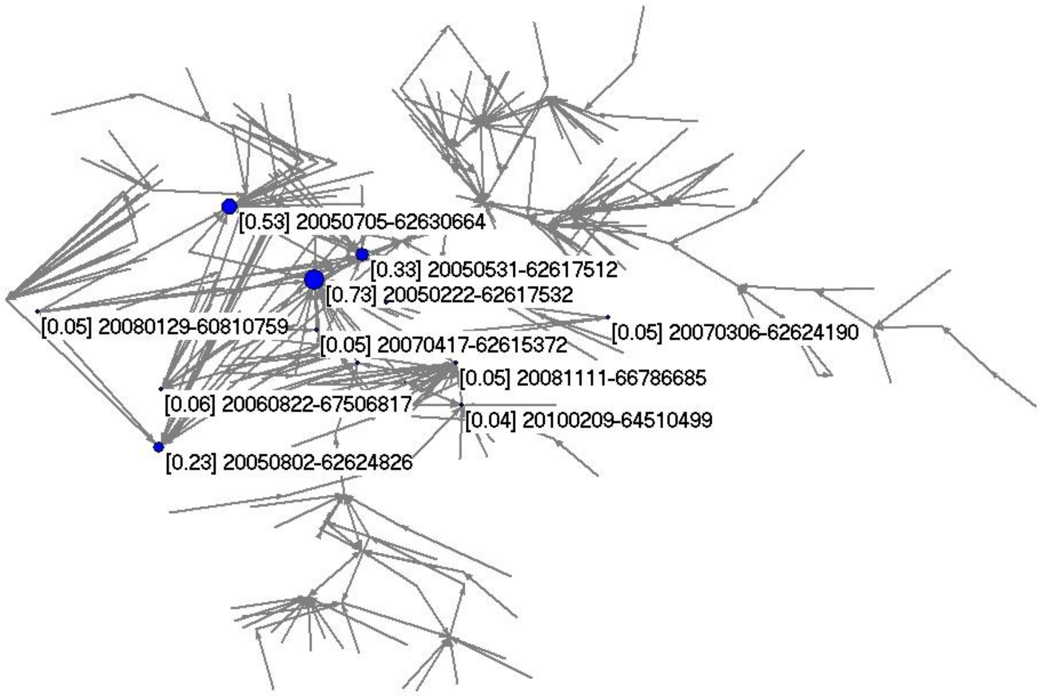

Figure 5.4.NP12. The authority patents of NP12

<u>Hub weights (Figure 5.5.NP12, Table 5.11.NP12)</u> – The best developments of the core inventions are the following patents (top 5):

- vertex 170, owned by the company Konarka Technologies, with the title 'Photovoltaic cells incorporating rigid substrates';
- vertex 26, owned by the University of Massachusetts, with the title 'Photovoltaic cell';

- vertex 53, owned Konarka Technologies, with the title 'Gel electrolytes for dye sensitized solar cells';
- vertex 10, which was also the fifth most authority patent;
- vertex 279, owned by the Industrial Technology Research Centre of Taiwan, with the title 'Method for manufacturing an electrode'.

Table 5.11.NP12. Top 10 hub patents of NP12

Rank	Vertex	Value	Id (Label)
1	170	0.33	20111206-65115576
2	26	0.33	20080129-60810759
3	53	0.28	20090811-67717404
4	10	0.28	20060822-67506817
5	279	0.27	20121218-76502749
6	249	0.23	20120830-80571571
7	101	0.15	20110104-69945392
8	59	0.14	20091013-64616008
9	209	0.14	20120501-71608482
10	45	0.14	20090421-64303645

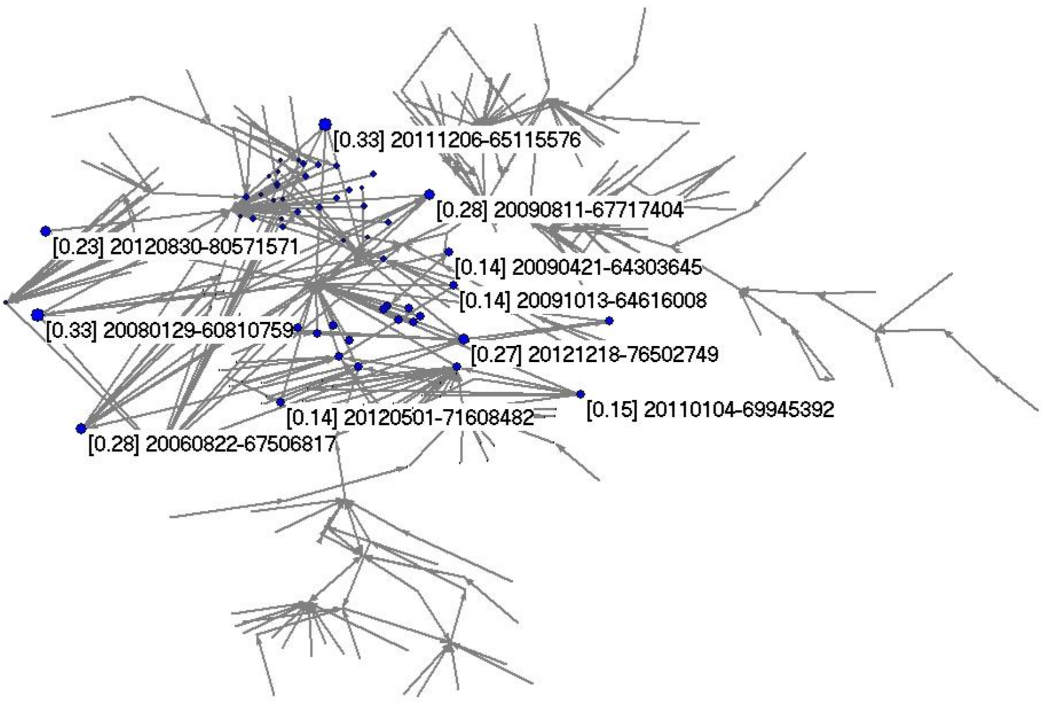

Figure 5.5.NP12. The hub patents of NP12

SPC (Figure 5.6.NP12, Table 5.12.NP12) - This network has 3 strong components which we shrank to obtain a new network to run the SPC algorithm. It highlights nine patents characterizing the technological trajectory of NP12. They are P12, and four authority patents already described (vertex 5, 6, 7 and 8), 2 hubs (vertex 8 and 279), and vertex 93, owned by the Georgia Technology Research Corporation, with the title 'Boron diffusion in silicon devices'.

Table 5.12.NP12 vertices on main path SPC [flow] of NP12

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000906-18053580
2	5	1	20050222-62617532
3	7	1	20050705-62630664
4	6	1	20050531-62617512
5	8	1	20050802-62624826
6	26	1	20080129-60810759
7	93	1	20100907-62078802
8	114	1	20110405-65561615
9	279	1	20121218-76502749

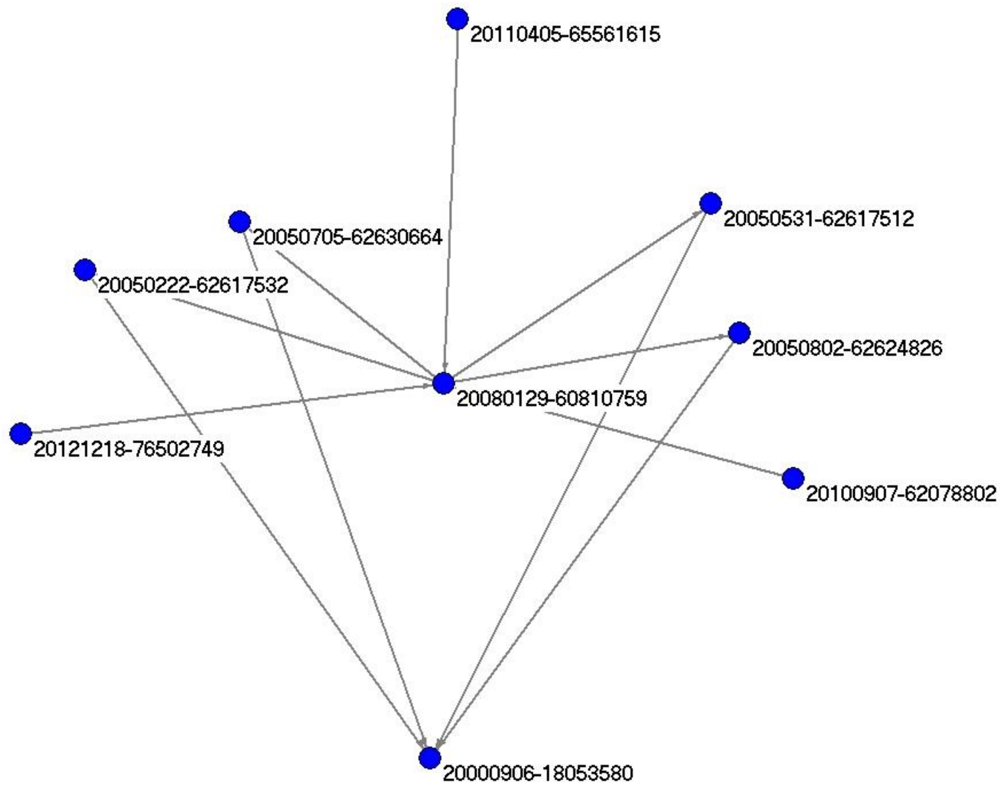

Figure 5.6.NP12. SPC of NP12

Network and connectivity analysis of network built on P14 (NP14)- 20001213-18055210

P14 was published in the EU in 2000 by the Japanese company, Kaneka Corporation. The title is 'Method of encapsulating a photovoltaic module by an encapsulating material' (H01L31/048; H01L31/18). NP14 is a small network made up by eight vertices and seven arcs.

Table 5.7.NP14. Characteristics

Number of vertices (n)	**8**
	Arcs
Total number of lines	7
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.10
Average degree	1.75

In-degree centrality (Figure 5.1.NP14; Table 5.8.NP14) – According to the in-degree centrality values, P14 the most cited patent.

Table 5.8.NP14. In-degree and out-degree centrality values of NP14

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	1(P14)	4	20001213-18055210	3	1	20080521-19246695
2	3	3	20080521-19246695	8	1	20120801-76314683
3				7	1	20120605-73511557
4				6	1	20111004-67865767
5				5	1	20100526-71737519
6				4	1	20091022-70336773
7				2	1	20080220-00311734

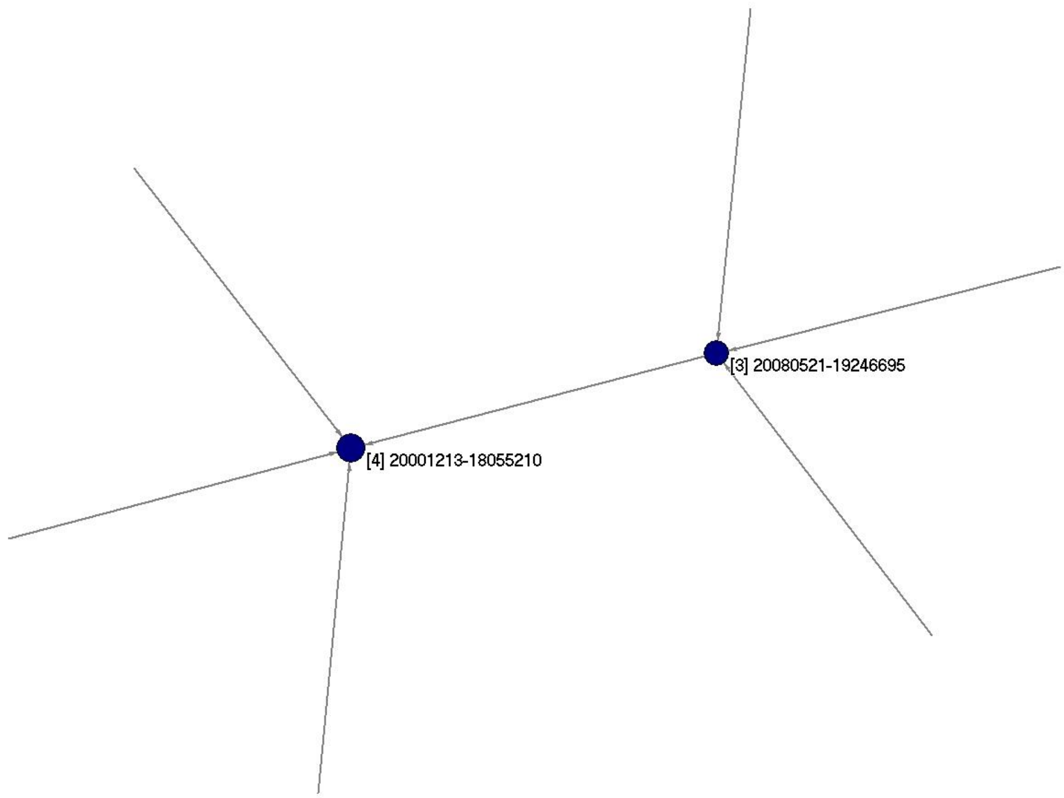

Figure 5.1.NP14. In-degree centrality of NP14

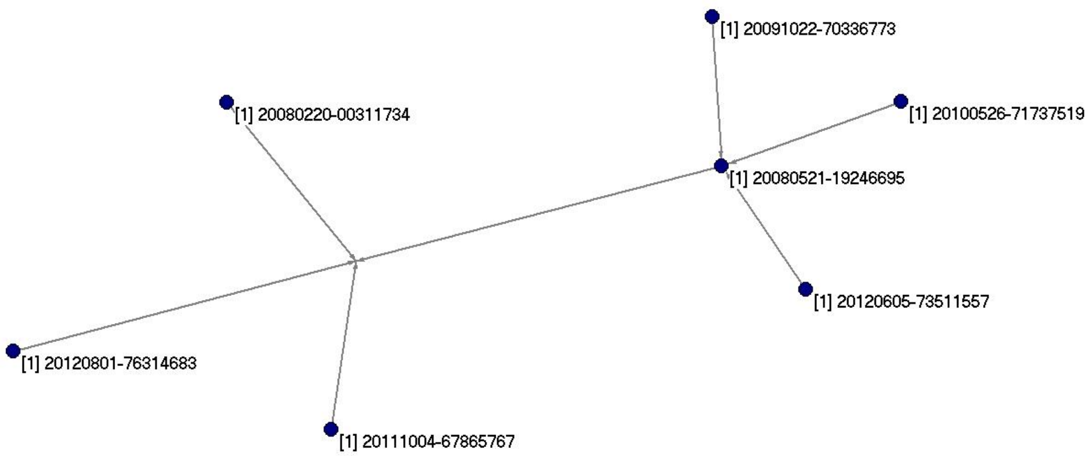

Figure 5.2.NP14. Out-degree centrality of NP14

Closeness centrality (Figure 5.3.NP14; Table 5.9.NP14) – P14 is ranked 1st in the top 10 patents according to the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP14, which shows P14 lying at the centre of the surrounding clusters.

Table 5.9.NP14. Closeness centrality values of NP14

Rank	Vertex	Value	Id (Label)
1	1 (P14)	0.70	20001213-18055210
2	3	0.70	20080521-19246695
3	7	0.43	20120605-73511557
4	6	0.43	20111004-67865767
5	5	0.43	20100526-71737519
6	4	0.43	20091022-70336773
7	8	0.43	20120801-76314683
8	2	0.43	20080220-00311734

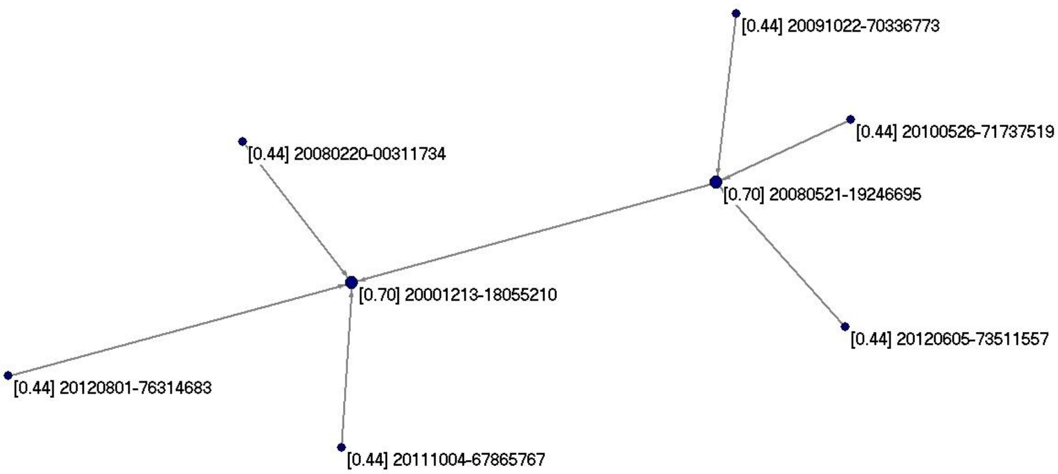

Figure 5.3.NP14. Closeness centrality of NP14

Authority weights (Figure 5.4.NP14; Table 5.10.NP14) – There are two authorities in NP14:

- P14 with the highest value (1);
- vertex 3, published in Europe by the Japanese NPC Corporation.

Table 5.10.NP14. The authority patents of NP14

Rank	Vertex	Value	Id (Label)
1	1 (P14)	1	20001213-18055210
2	3	0.02	20080521-19246695

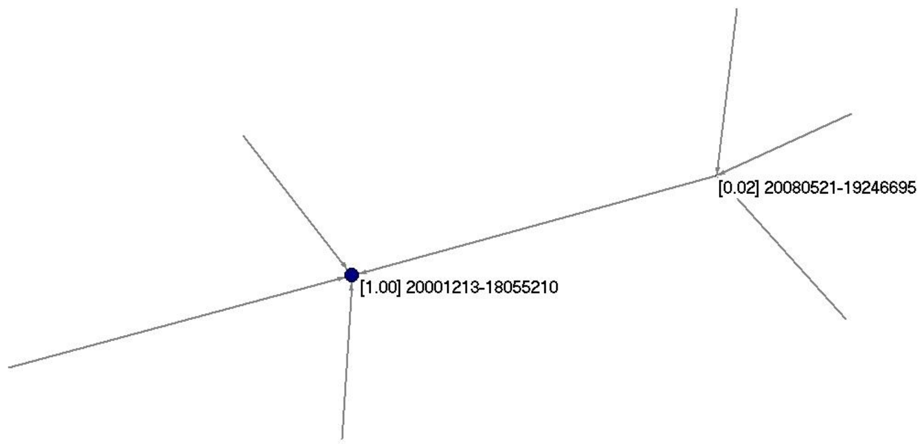

Figure 5.4.NP14. The authority patents of NP14

Hub weights (Figure 5.5.NP14; Table 5.11.NP14) – The top five best developments of the two core inventions previously identified are:

- vertex 3, the second authority;
- vertex 6, published in Europe by the NPC Corporation, with the title 'Laminating apparatus';
- vertex 2, published in the US by the NPC Corporation, with the title 'Laminating apparatus';

- vertex 8, published in Europe by Eurocopter Deutschland with the title 'Device and method for manufacturing of preimpregnated preform and multi-layer preimpregnated preform resulting from said method';
- vertex 4, published simultaneously in several countries, by the German Meier Solutions GmbH, with the title 'Laminating unit with heating and cooling device and method for the operation thereof'.

Table 5.11.NP14. The hub patents of NP14

Rank	Vertex	Value	Id (Label)
1	3	0.50	20080521-19246695
2	6	0.50	20111004-67865767
3	2	0.50	20080220-00311734
4	8	0.50	20120801-76314683
5	4	0.01	20091022-70336773
6	7	0.01	20120605-73511557
7	5	0.01	20100526-71737519

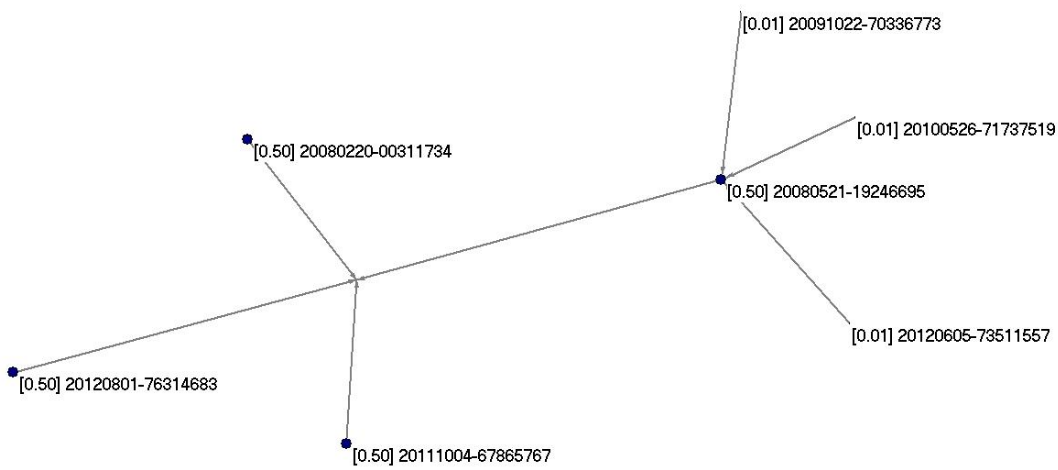

Figure 5.5.NP14. The hub patents of NP14

<u>*SPC (Figure 5.6.NP14; Table 5.12.NP14)*</u> – The technological trajectory comprises all eight patents. This goes from P8 to the most recent patent '20120605-73511557'. This is a patent

published in US by Komax Holding, with the title 'Apparatus for laminating a solar module'.

Table 5.12.NP14. Vertices on main path SPC [flow] of NP14

Rank	Vertex	Cluster	Id (Label)
1	1	1	20001213-18055210
2	2	1	20080220-00311734
3	3	1	20080521-19246695
4	4	1	20091022-70336773
5	5	1	20100526-71737519
6	6	1	20111004-67865767
7	7	1	20120605-73511557
8	8	1	20120801-76314683

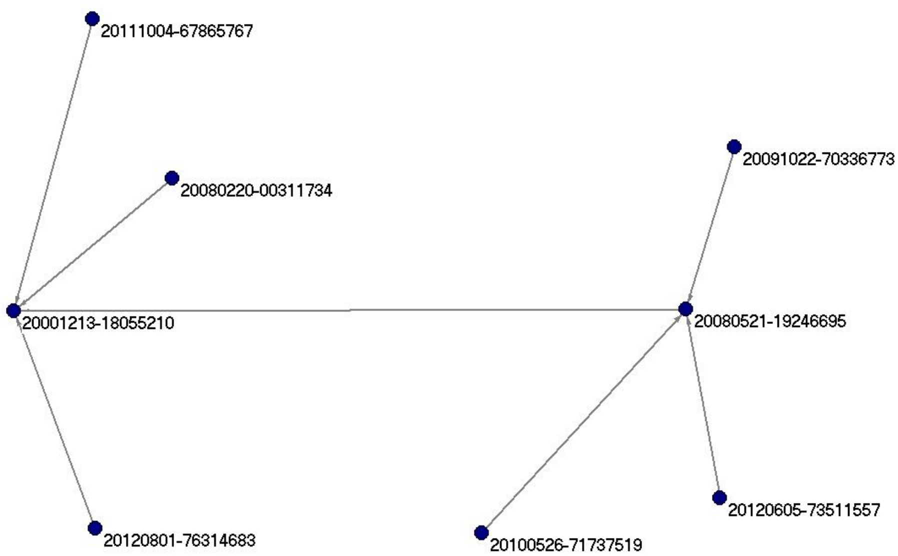

Figure 5.6.NP14. SPC of NP14

<u>Network and connectivity analysis of network built on P15 (NP15) - 20001115-18056678</u>

P15 is the European patent published by the Japanese Kaneka Corporation, with the title 'Reverse biasing apparatus for solar battery module'. NP15 is a very small network, its characteristics are give in Table 5.7.NP15.

Table 5.7.NP15. Characteristics

Number of vertices (n)	**2**
	Arcs
Total number of lines	1
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.25
Average degree	1.4

Table 5.8.NP15. In-degree and out-degree centrality values of NP15

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	1 (P15)	1	20001115-18056678	2	1	20120313-71342946

Figure 5.1.NP15. In-degree centrality of NP15

Figure 5.2.NP15. Out-degree centrality of NP15

<u>*Closeness centrality (Figure 5.3.NP15, Table 5.9.NP15)*</u> – According to the closeness centrality, the two patents have the same value (1).

Table 5.9.NP15. Closeness centrality values of NP15

Rank	**Vertex**	**Value**	**Id (Label)**
1	1 (P15)	1	20001115-18056678
2	2	1	20120313-71342946

Figure 5.3.NP15. Closeness centrality of NP15

Authority weights (Figure 6.4.MP15, Table 5.10.NP15) – P15 is the authority in NP15.

Table 5.10.NP15. The authority patent of NP15

Rank	Vertex	Value	Id (Label)
1	1 (P15)	1	20001115-18056678

Figure 5.4.NP15. The authority patent of NP15

Hub weights (Figure 5.5.NP15, Table 5.11.NP15) – The hub patent is vertex 2 published in the US by the Japanese Sharp Corporation, with the title 'Reverse bias processing apparatus and reverse bias processing method for photoelectric conversion devices'.

Table 5.11.NP15. The hub patent of NP15

Rank	Vertex	Value	Id (Label)
1	2	1	20120313-71342946

Figure 5.5.NP15. The hub patent of NP15

SPC (Figure 5.6.NP15, Table 5.12.NP15) – Both patents are on the technological trajectory of NP15.

Table 5.12.NP15. Vertices on main path [flow] of NP15

Rank	Cluster	Id (Label)
1	1	20001115-18056678
2	1	20120313-71342946

Figure 5.6.NP15. SPC of NP15

Network and connectivity analysis of network built on P16 (NP16)- 20001018-18056943

P16 is a European patent EP1045455, owned by the German company Angewandte Solarenergie - ASE GmbH Produktzentrum Phototronics, with the title 'Circuit arrangement for power generation with solar cells' (IPC: H01L31/04, H01L31/042). The characteristics of NP16 are described in Table 5.7.NP16.

Table 5.7.NP16. Characteristics

Number of vertices (n)	**45**
	Arcs
Total number of lines	45
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.02
Average degree	2.00

<u>*In-degree centrality (Figure 5.1.NP16, Table 5.8.NP16)*</u> – P16 is the fourth most cited patent in NP16, the most cited patent (vertex 2), owned by two German private inventors, with the title 'Circuit arrangement for a photovoltaic system'.

Table 5.8.NP16. Top 10 in-degree and out-degree centrality values of NP16

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	2	15	20031127-10767285	6	2	20090423-00541549
2	3	9	20060803-21480844	36	2	20120515-75165998
3	11	6	20100504-64360811	44	1	20121113-78039768
4	1 (P16)	4	20001018-18056943	43	1	20121101-79670163
5	8	3	20091210-71832214	42	1	20121030-76881474
6	18	2	20110324-74656933	41	1	20121030-74174765
7	29	1	20111115-72522286	40	1	20120802-80364591
8	5	1	20081127-68646935	7	1	20090708-19250029
9	40	1	20120802-80364591	38	1	20120607-78362094
10	19	1	20110419-70531128	37	1	20120523-75109920

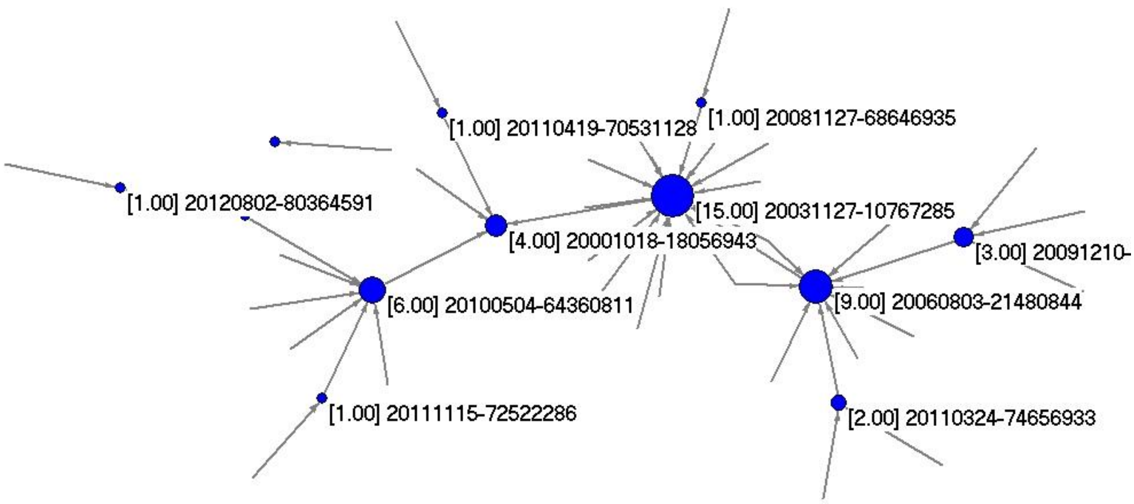

Figure 5.1.NP16. In-degree centrality of NP16

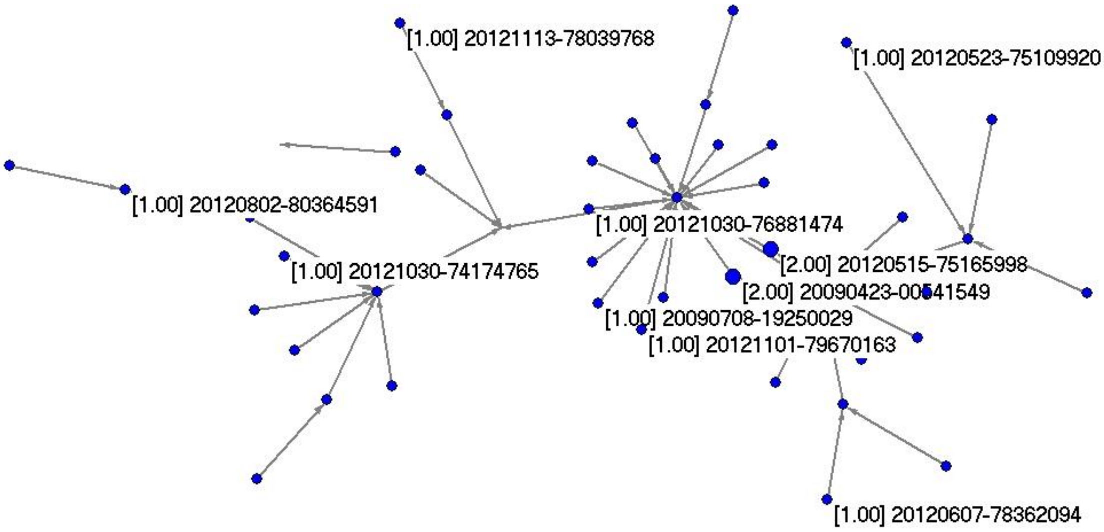

Figure 5.2.NP16. Out-degree centrality of NP16

<u>*Closeness centrality (Figure 5.3.NP16, Table 5.9.NP16)*</u> – P16 is ranked third according to the closeness centrality values, with a value of 0.39. Vertex 3 has the same value, while vertex 2 is ranked 1st for closeness centrality, with a value of 0.46, and is also the most cited patent.

Table 5.9.NP16. Top 10 closeness centrality values of NP16

Rank	Vertex	Value	Id (Label)
1	2	0.46	20031127-10767285
2	3	0.39	20060803-21480844
3	1 (P16)	0.39	20001018-18056943
4	6	0.34	20090423-00541549
5	36	0.34	20120515-75165998
6	11	0.32	20100504-64360811
7	5	0.31	20081127-68646935
8	7	0.31	20090708-19250029
9	15	0.31	20101202-73784326
10	14	0.31	20101128-71798628

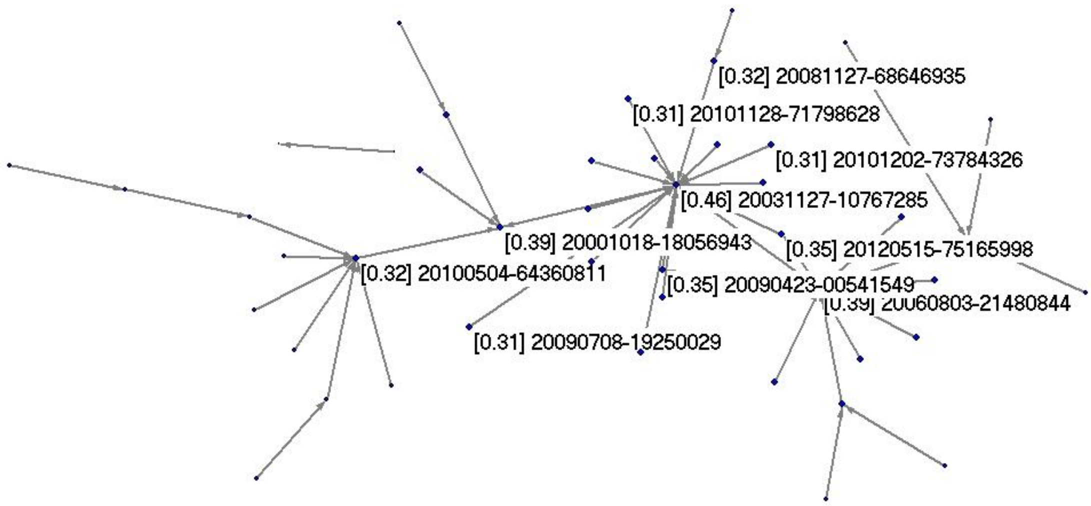

Figure 5.3.NP16. Closeness centrality values of NP16

<u>*Authority weights (Figure 5.4.NP16, Table 5.10.NP16)*</u> – There are two authority patents in NP16.

- vertex 2, which has been described as the most cited;
- vertex 3, published simultaneously in different countries, by German inventors, with the title 'Protective circuit'.

Table 5.10.NP16. The authority patents of NP16

Rank	**Vertex**	**Value**	**Id (Label)**
1	2	0.96	20031127-10767285
2	3	0.29	20060803-21480844

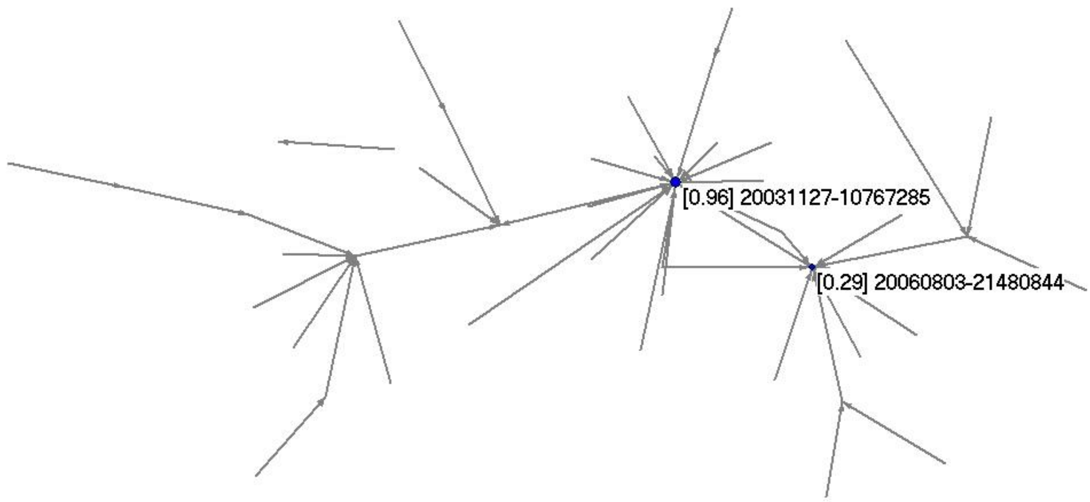

Figure 5.4.NP16. The authority patents of NP16

<u>Hub weights (Figure 5.5.NP16, Table 5.11.NP16)</u> – The best developments of the core inventions previously identified are listed in Table 5.11.NP16. The first two patents obtain the same value of 0.32. They are:

- vertex 6, owned by three German inventors, with the title 'Controllable switch-over device for a solar module';
- the second hub vertex 36 is a second version of the previous patent;

All the other patents obtained a value of 0.24:

- vertex 7, owned by the German company SMA Solar Technology, with the title 'Evaluation Method';
- vertex 15, owned by two Italian inventors, with the title 'Apparatus and method for managing and conditioning photovoltaic power harvesting systems';
- vertex 14, this patent is a second version of the previous one.

Table 5.11.NP16. Top 10 hub patents of NP16

Rank	Vertex	Value	Id (Label)
1	6	0.32	20090423-00541549
2	36	0.32	20120515-75165998
3	7	0.24	20090708-19250029
4	15	0.24	20101202-73784326
5	14	0.24	20101128-71798628
6	3	0.24	20060803-21480844
7	13	0.24	20101111-71152822
8	26	0.24	20110930-73606999
9	25	0.24	20110929-76698260
10	24	0.24	20110928-76606315

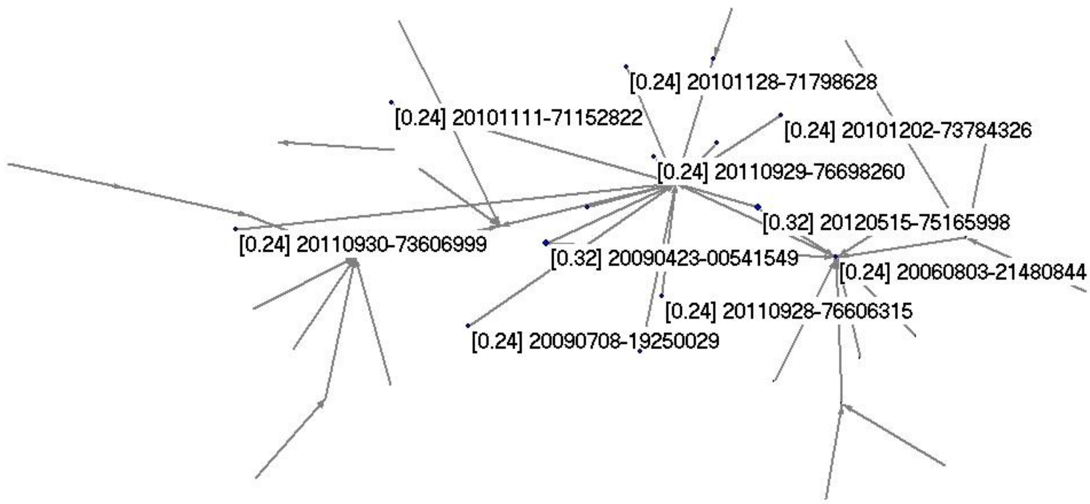

Figure 5.5.NP16. The hub patents of NP16

<u>*SPC (Figure 5.6.NP16, Table 5.12.NP16)*</u> – Figure 5.6.NP16 shows the technological trajectory in NP16, which includes all 45 patents. It goes from P16 to the patent (vertex 44) published in France by Mersen France SB SAS, with the title 'System for supplying direct current and DC voltage protected by a current limiter, and method for protecting same'.

Table 5.12.NP16 vertices on main path SPC [flow] of NP16

Rank	Vertices	Cluster	Id (Label)
1	1	1	20001018-18056943
2	2	1	20031127-10767285

3	3	1	20060803-21480844
4	4	1	20070425-18056941
5	5	1	20081127-68646935
6	6	1	20090423-00541549
7	7	1	20090708-19250029
8	8	1	20091210-71832214
9	9	1	20100317-71473114
10	10	1	20100318-73079085
11	11	1	20100504-64360811
12	12	1	20101104-74999487
13	13	1	20101111-71152822
14	14	1	20101128-71798628
15	15	1	20101202-73784326
16	16	1	20110120-75708289
17	17	1	20110202-71078513
18	18	1	20110324-74656933
19	19	1	20110419-70531128
20	20	1	20110603-75675041
21	21	1	20110609-75392524
22	22	1	20110630-77170098
23	23	1	20110824-73607041
24	24	1	20110928-76606315
25	25	1	20110929-76698260
26	26	1	20110930-73606999
27	27	1	20111011-71494243
28	28	1	20111110-76493569
29	29	1	20111115-72522286
30	30	1	20111115-74652024
31	31	1	20111208-77208012
32	32	1	20111214-73580791
33	33	1	20120117-72524087
34	34	1	20120315-77280293
35	35	1	20120320-76211801
36	36	1	20120515-75165998
37	37	1	20120523-75109920
38	38	1	20120607-78362094
39	39	1	20120614-79897849
40	40	1	20120802-80364591
41	41	1	20121030-74174765
42	42	1	20121030-76881474
43	43	1	20121101-79670163
44	44	1	20121113-78039768
45	45	1	20121123-77441696

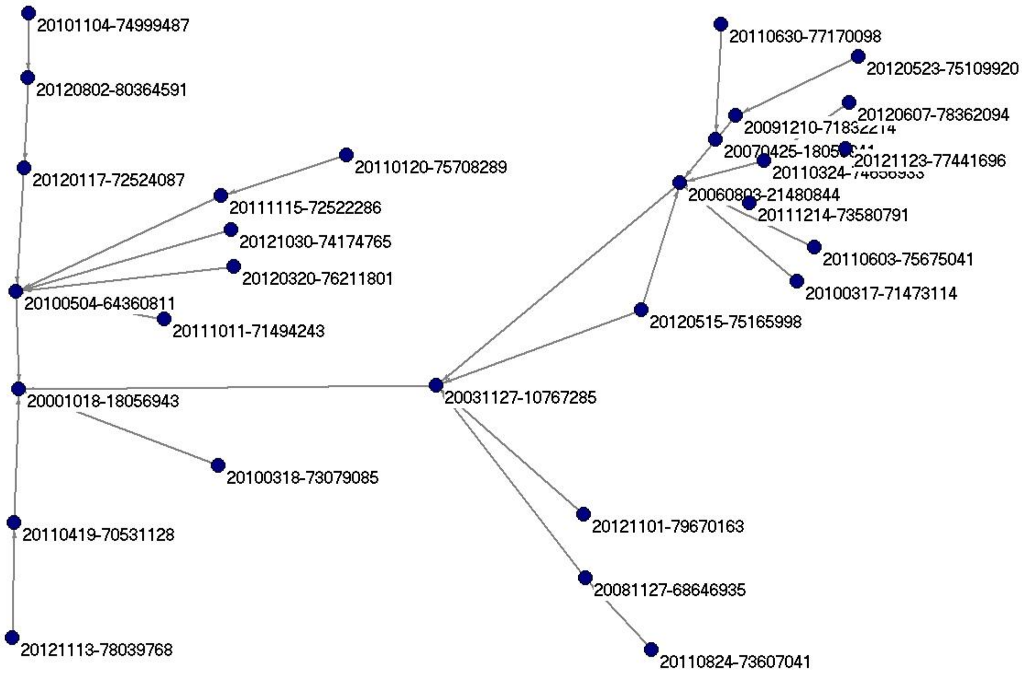

Figure 5.6.NP16. SPC of NP16

<u>Network and connectivity analysis of network built on P17 (NP17)</u> **<u>- 20001129-18057201</u>**

P17 is patent EP1056138, published by the Japanese Canon KK Corporation with the title 'Solar cell module solar cell-bearing roof and solar cell power generation system' (IPC: H01L31/048). NP17 characteristics are displayed in Table 5.7.NP17.

Table 5.7.NP17. Characteristics

Number of vertices (n)	**22**
	Arcs
Total number of lines	21
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.04
Average degree	1.90

<u>*In-degree centrality (Figure 5.1.NP17, Table 5.8.NP17)*</u> – According to the in-degree centrality values, P17 is the second most cited patent, the first being a patent (vertex 4) owned by the American Research Institute of Palo Alto, with the title 'Bifacial cell with extruded gridline metallization'.

Table 5.8.NP17. In-degree and out-degree centrality values of NP17

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	4	7	20071107-19257598	3	1	20031008-18655117
2	1	5	20001129-18057201	22	1	20121005-81179653
3	3	4	20031008-18655117	21	1	20120531-78957110
4	7	3	20091008-70265904	20	1	20001220-00495792
5	5	1	20090611-70388965	19	1	20111213-71234854
6	19	1	20111213-71234854	18	1	20111111-73785839
7				17	1	20111110-76835881
8				16	1	20110929-77634561
9				7	1	20091008-70265904
10				15	1	20110915-73127946

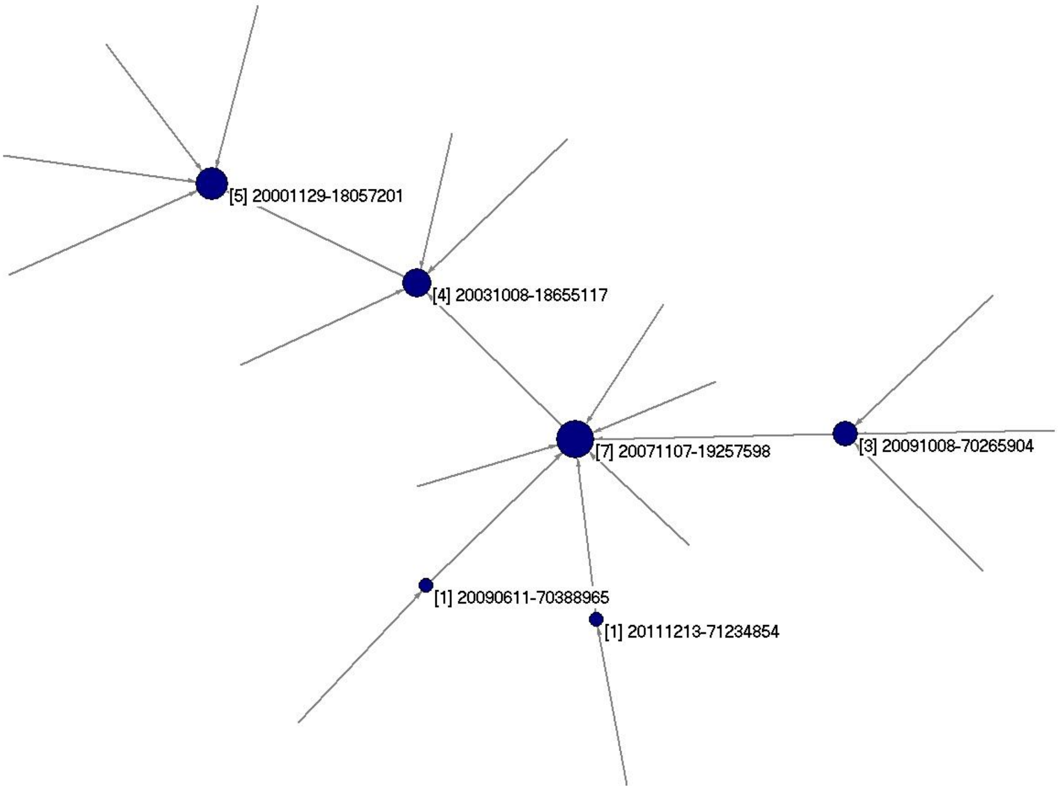

Figure 5.1.NP17. In-degree centrality of NP17

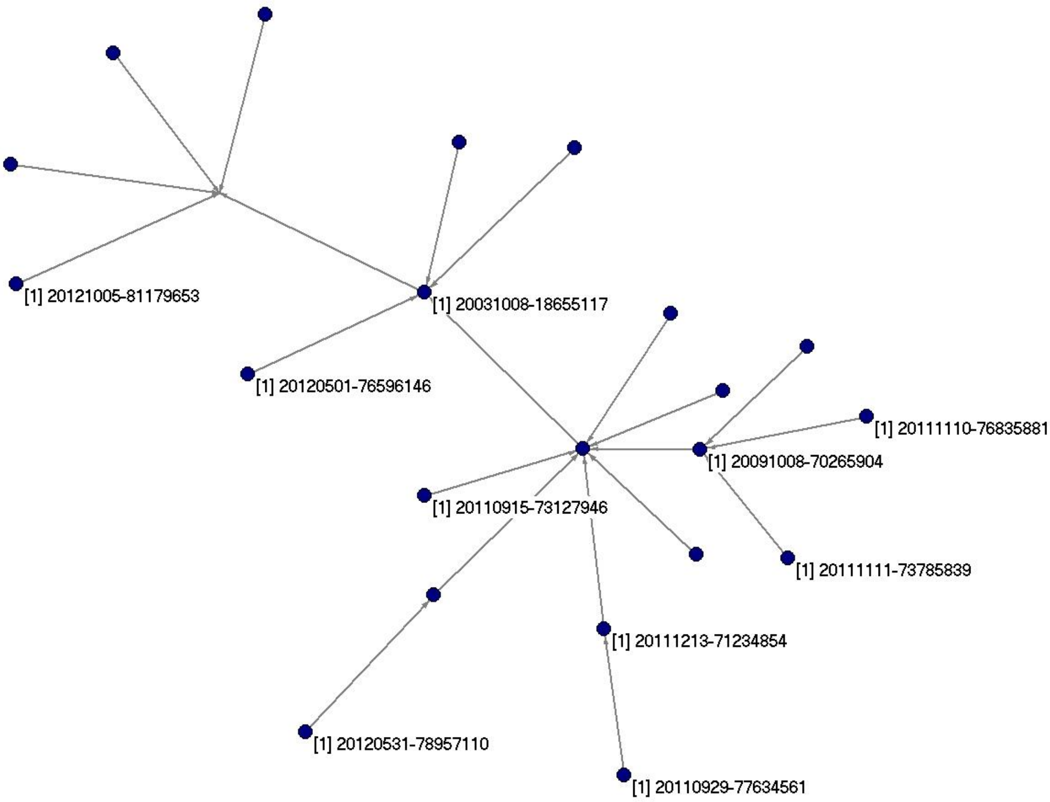

Figure 5.2.NP17. Out-degree centrality of NP17

Closeness centrality (Figure 5.3.NP17, Table 5.9.NP17) – According to the closeness centrality values P17 occupies fourth position, while first position is occupied by vertex 4, already mentioned as the most cited.

Table 5.9.NP17. Top 10 closenss centrality values of NP17

Rank	Vertex	Value	Id (Label)
1	4	0.55	20071107-19257598
2	3	0.50	20031008-18655117
3	7	0.40	20091008-70265904
4	1 (P17)	0.38	20001129-18057201
5	5	0.37	20090611-70388965
6	19	0.37	20111213-71234854
7	15	0.36	20110915-73127946
8	11	0.36	20101111-74820030
9	10	0.36	20101111-73523294
10	9	0.36	20100204-72000044

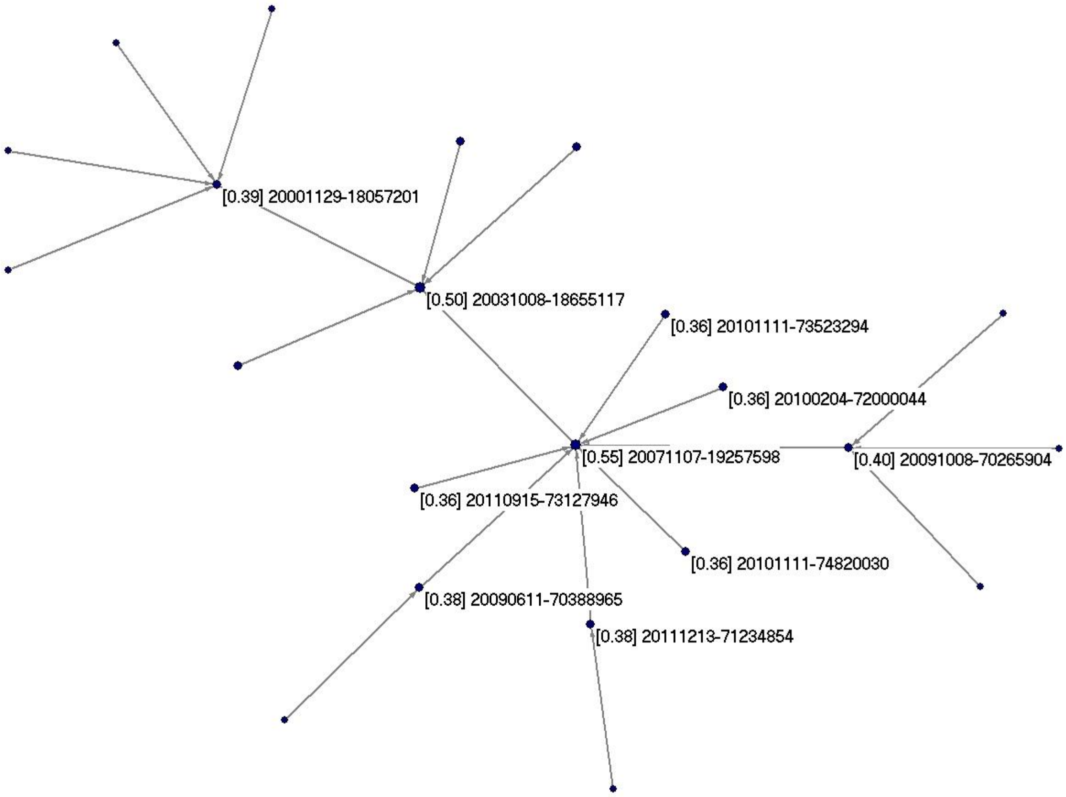

Figure 5.3.NP17. Closeness centrality of NP17

<u>*Authority weights (Figure 5.4.NP17, Table 5.10.NP17)*</u> – There are two authority patents in NP17. The first is vertex 4, already described as the most cited according to the in-degree and closeness centrality values. P17 is the second one.

Table 5.10.NP17. The authority patents of NP17

Rank	**Vertex**	**Value**	**Id (Label)**
1	4	1	20071107-19257598
2	1 (P17)	0.02	20001129-18057201

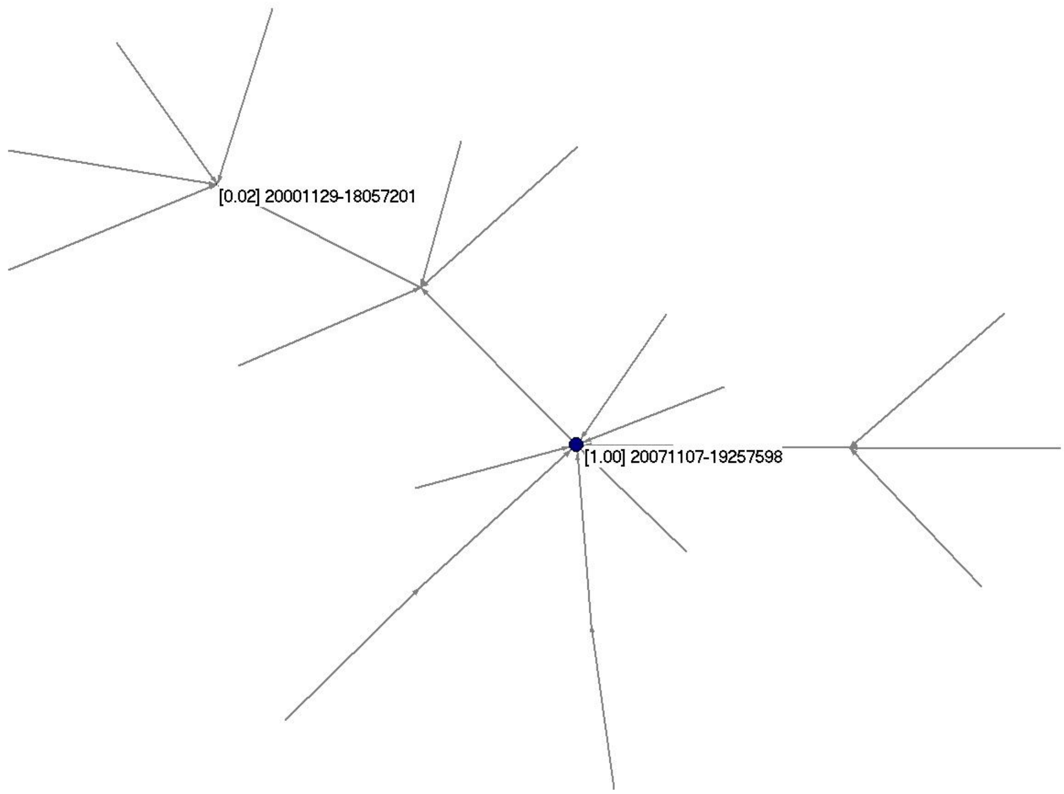

Figure 5.4.NP17. The authority patents of NP17

<u>*Hub weights (Figure 5.5.NP17, Table 5.11.NP17)*</u> – There are seven best developments of the previous core invention, which are depicted in Figure 5.5.NP17. They have the same value (0.38). The first five are:

- vertex 7, owned by the University of Stuttgart, with the title 'Photovoltaic solar cell and method of production thereof';
- vertex 15, owned by four private inventors, with the title 'Method and in-line production system for the production of solar cells'
- vertex 5, owned by two German inventors, with the title 'Method for metalizing solar cells, hot-melt aerosol ink, and aerosol jet printing system';
- vertex 11, owned by the German Inventux Technologies, with the title 'Solar cell, has layer system arranged between transparent substrate i.e. glass substrate, and

cover, and reflector layer arranged between laminate layer and cover or integrated with laminate layer or cover';

- vertex 10, owned by the German Inventux Technologies, with the title 'Solar cell and method for production thereof'.

Table 5.11.NP17. The hub weights of NP17

Rank	Vertex	Value	Id (Label)
1	7	0.38	20091008-70265904
2	15	0.38	20110915-73127946
3	5	0.38	20090611-70388965
4	11	0.38	20101111-74820030
5	10	0.38	20101111-73523294
6	9	0.38	20100204-72000044
7	19	0.38	20111213-71234854

Figure 5.5.NP17. The hub patents of NP17

<u>*SPC (Figure 5.6.NP17, Table 5.12.NP17)*</u> – The SPC highlights all 22 patents as characterizing the technological trajectory of NP17. Patents are listed in Table 5.12.NP17.

Figure 5.6.NP17 shows the trajectory with three focal points from which the others depart. The first focal point is P17, the second is vertex 3, owned by the Japanese Sanyo Electric Corporation with the title 'Solar cell module', the third focal point is vertex 4 which has been described as the most cited and the first authority in NP17.

Table 5.12.NP17. Vertices on main path SPC [flow] of NP17

Rank	Vertex	Cluster	Id (Label)
1	1	1	20001129-18057201
2	2	1	20020703-18280178
3	3	1	20031008-18655117
4	4	1	20071107-19257598
5	5	1	20090611-70388965
6	6	1	20090902-68677664
7	7	1	20091008-70265904
8	8	1	20100107-71152651
9	9	1	20100204-72000044
10	10	1	20101111-73523294
11	11	1	20101111-74820030
12	12	1	20110112-72232241
13	13	1	20110408-73357903
14	14	1	20110803-73574625
15	15	1	20110915-73127946
16	16	1	20110929-77634561
17	17	1	20111110-76835881
18	18	1	20111111-73785839
19	19	1	20111213-71234854
20	20	1	20120501-76596146
21	21	1	20120531-78957110
22	22	1	20121005-81179653

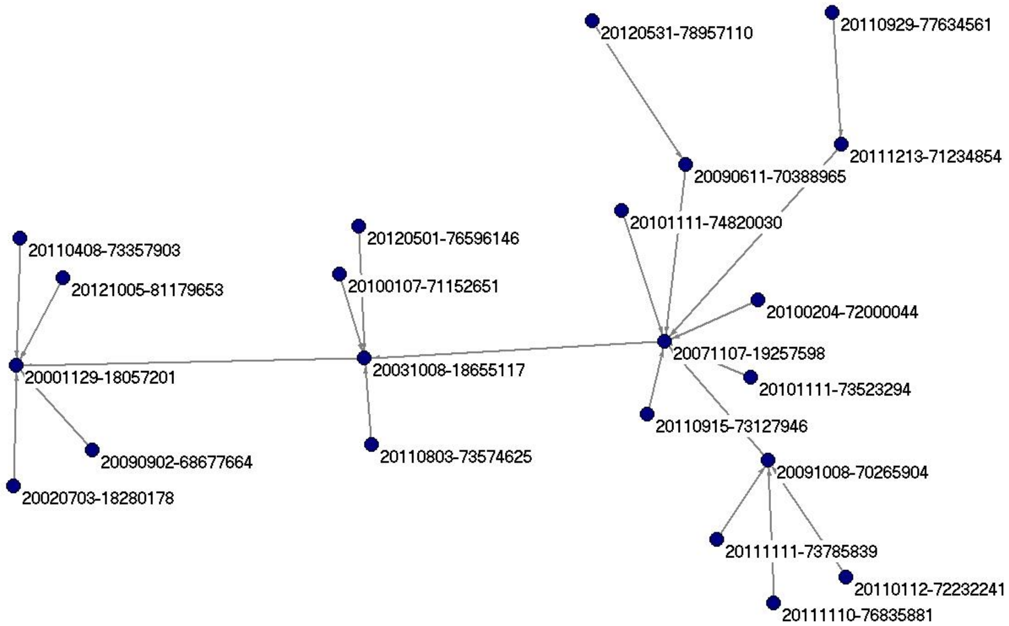

Figure 5.6.NP17. SPC of NP17

Network and connectivity analysis of network built on P18 (NP18) - 20001108-18062685

P18 is patent EP1050910 owned by the German company Assignee Webasto Vehicle Systems International GmbH with the title 'Solar module adapted to be installed on vehicles and method of its fabrication'. NP18 characteristics are given in Table 5.7.NP18 .

Table 5.7.NP18. characteristics

Number of vertices (n)	**10**
	Arcs
Total number of lines	10
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.10
Average degree	2.00

In-degree centrality (Figure 5.1.NP18, Table 5.8.NP18) – P18 is the most cited patent in NP18, with six citations, followed by two other patents with two citaions each. The second is vertex 3, owned by the Japanese Affinity Co., with the title 'Solar cell module and method for manufacturing the same', and vertex 4, owned by the French company Peugeot Citroen Automobiles with the title 'Flexible roof for e.g. electric vehicle, has main part with photovoltaic cells transforming solar energy into electric energy to power part of electrical equipments of vehicle, where part is flexible and foldable during opening of roof'.

Table 5.8.NP18. In-degree and out-degree centrality values of NP18

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	1(P18)	6	20001108-18062685	6	2	20120112-78775940
2	3	2	20090723-70978297	10	1	20121206-81340098
3	4	2	20100129-68701992	9	1	20120907-80633330
4				8	1	20120524-78269265
5				7	1	20120119-79146905
6				3	1	20090723-70978297
7				5	1	20120105-78738631
8				4	1	20100129-68701992
9				2	1	20080529-68287804
10				6	2	20120112-78775940

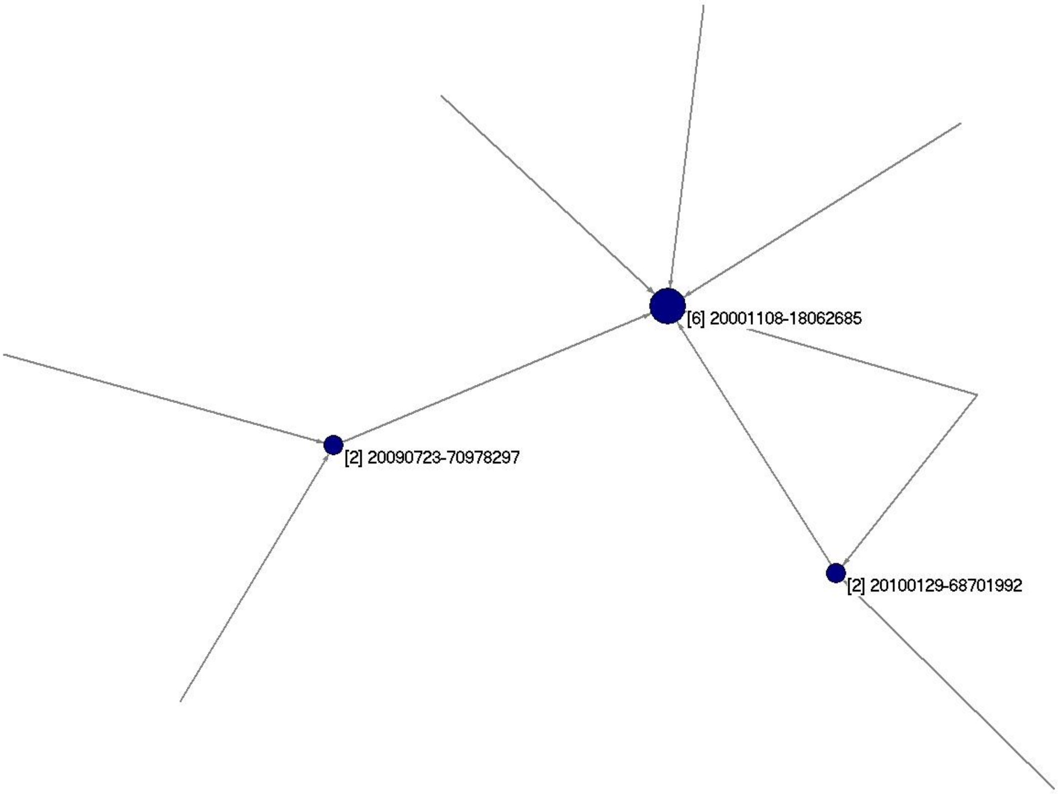

Figure 5.1.NP18. In-degree centrality of NP18

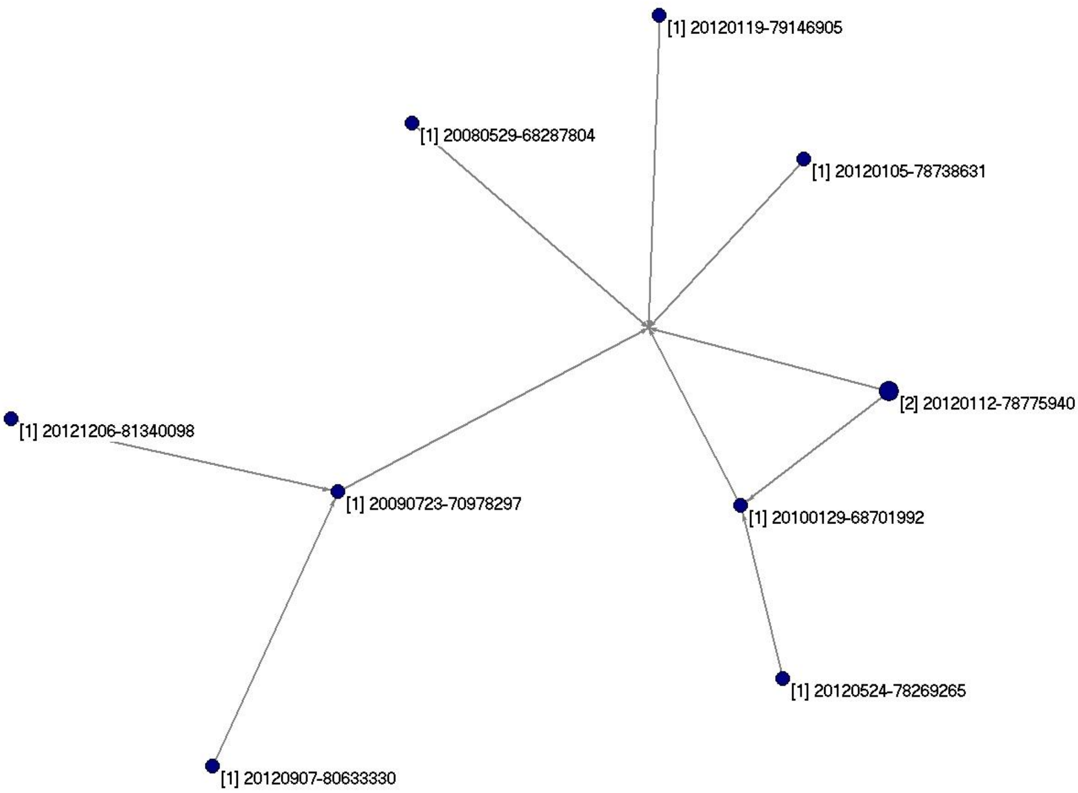

Figure 5.2.NP18. Out-degree centrality of NP18

<u>*Closeness centrality (Figure 5.3.NP18, Table 5.9.NP18)*</u> – P18 is the first among the top 10 patents according to the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP18, which shows P18 lying at the centre of the surrounding clusters.

Table 5.9.NP18. Top 10 closeness centrality values of NP18

Rank	Vertex	Value	Id (Label)
1	1 (P18)	0.75	20001108-18062685
2	3	0.56	20090723-70978297
3	4	0.53	20100129-68701992
4	6	0.50	20120112-78775940
5	7	0.45	20120119-79146905
6	5	0.45	20120105-78738631
7	2	0.45	20080529-68287804
8	10	0.37	20121206-81340098
9	9	0.37	20120907-80633330
10	8	0.36	20120524-78269265

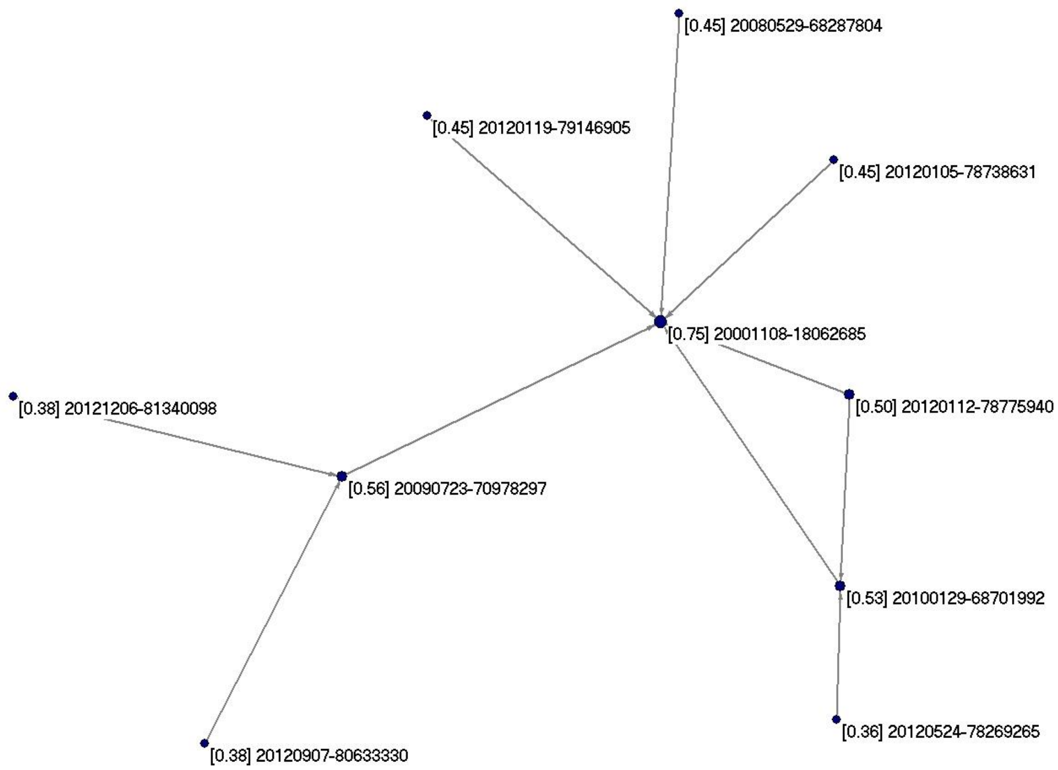

Figure 5.3.NP18. Closeness centrality of NP18

<u>Authority weights (Figure 5.4.NP18, Table 5.10.NP18)</u> – There are two authority patents along NP18. The first is P18 with a value of 0.97, and the second is vertex 4 with the value 0.23, and already described as the 3rd most cited patent in NP18.

Table 5.10.NP18. The authority patents of NP18

Rank	Vertex	Value	Id (Label)
1	1 (P18)	0.97	20001108-18062685
2	4	0.23	20100129-68701992

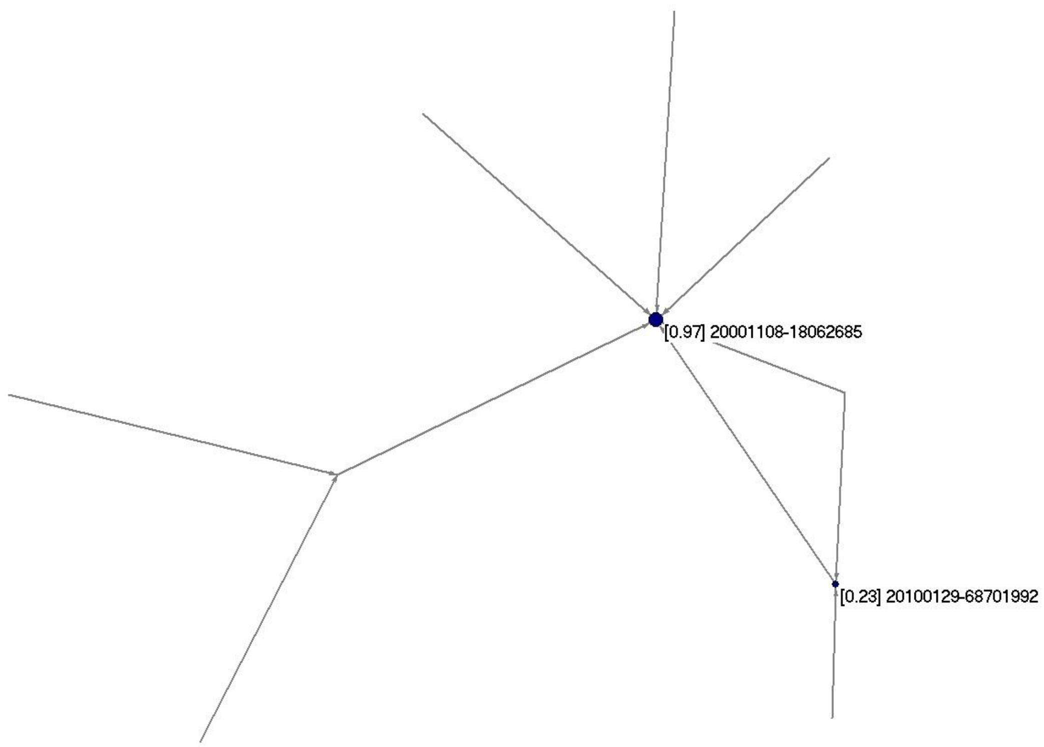

Figure 5.4.NP18. The authority patents of NP18

<u>Hub weights (Figure 5.5.NP18, Table 5.11.NP18)</u> – There are seven hub patents within NP18. The top five are:

- vertex 6, published in Germany by the American company Global Tech Operations, with the title ‘Folding roof arrangement for motor vehicle, has hood, which has hood segments that are successively foldable in opening position of hood and formed flexible, in which solar module is integrated’;
- vertex 7, published in Germany by a German inventor, with the title ‘System for converting solar energy into electrical energy for e.g. mobile container, utilized as mobile emergency power unit for supplying power in building, has photovoltaic device attached at outer surface of locomotive unit’;
- vertex 3, published simultaneously in several different countries by the Japanese company Affinity Co., with the title ‘Solar cell module and method for manufacturing the same’;
- vertex 2, published simultaneously in several different countries by the American BP Corporation, with title ‘Cable connectors for a photovoltaic module and method of installing’;
- vertex 5, published in Germany by a German inventor, with the title ‘System for converting solar energy into electrical energy for e.g. mobile container, utilized as mobile emergency power unit for supplying power in building, has photovoltaic device attached at outer surface of locomotive unit’.

Table 5.11.NP18. The hub patents of NP18

Rank	Vertex	Value	Id (Label)
1	6	0.48	20120112-78775940
2	7	0.39	20120119-79146905
3	3	0.39	20090723-70978297
4	2	0.39	20080529-68287804
5	5	0.39	20120105-78738631
6	4	0.39	20100129-68701992
7	8	0.09	20120524-78269265

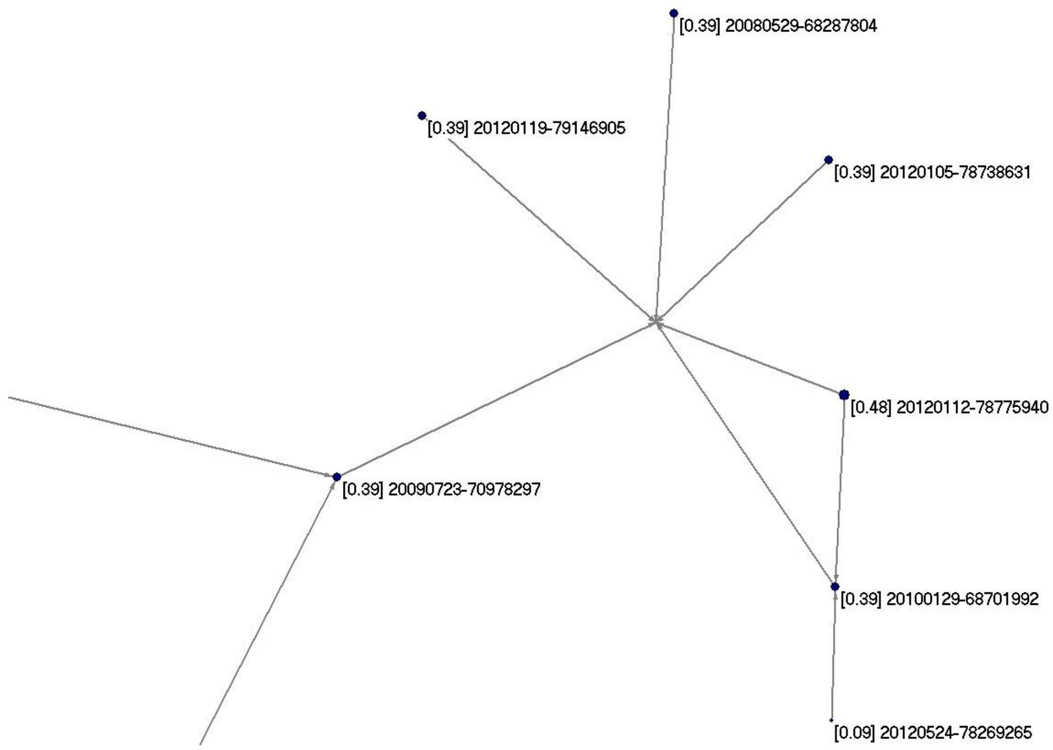

Figure 5.5.NP18. The hub patents of NP18

<u>*SPC (Figure 5.6.NP18, Table 5.12.NP18)*</u> – Figure 5.6.NP18 shows the technological trajecory of NP18 and its 10 patents. This starts with P18 from which many other patents depart. It is also the first authority patent in NP18. The second authority (vertex 4) represents a second focal point.

Table 5.12.NP18. Vertices on main path SPC [flow] of NP18

Rank	**Vertex**	**Cluster**	**Id (Label)**
1	1	1	20001108-18062685
2	2	1	20080529-68287804
3	3	1	20090723-70978297
4	4	1	20100129-68701992
5	5	1	20120105-78738631
6	6	1	20120112-78775940
7	7	1	20120119-79146905
8	8	1	20120524-78269265
9	9	1	20120907-80633330
10	10	1	20121206-81340098

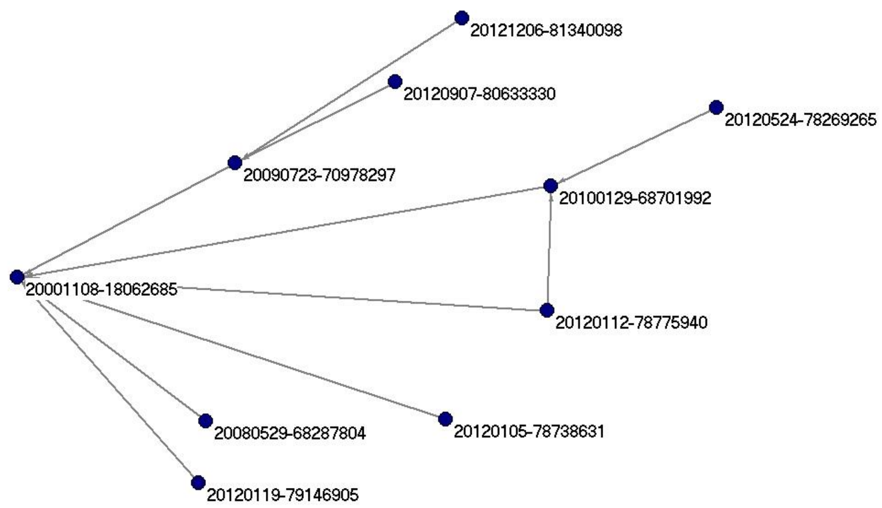

Figure 5.6.NP18. SPC of NP18

Network and connectivity analysis of network built on P19 (NP19) - 20000719-18096449

P19 was published in Europe by the company Ubbink Nederland with the title 'Assembly with photovoltaic panel for a roof' (IPC: H01L31/042). NP19 characteristics are given in Table 5.7.NP19.

Table 5.7.NP19. Characteristics

Number of vertices (n)	**21**
	Arcs
Total number of lines	21
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.04
Average degree	2.00

In-degree centrality (Figure 5.1.NP19, Table 5.8.NP19) – P19 is the most cited patent in NP19 with eight citations, followed by four other patents. The 2nd and 3rd most cited, obtained four citations. They are vertex 5, owned by the French company Solar Composites, with the original title 'Dispositif support de penneaux photovoltaiques sur une toiture, comprenant des moyens supports autorisant une circulation d'aire entre un plan de base et le panneau photovoltaique', and vertex 11, owned by two private inventors, with the title 'Roof panel with an integrated solar panel and roof comprising such panels'.

Table 5.8.NP19. In-degree and out-degree centrality values of NP19

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	1 (P19)	8	20000719-18096449	4	2	20080917-00125433
2	5	4	20090403-23646531	21	1	20080515-29436452
3	11	4	20100429-70442892	20	1	20120706-76247060
4	3	3	20060531-00360230	19	1	20120412-77730794
5	7	2	20090506-69650748	18	1	20120409-75523870
6				17	1	20120113-75955722
7				16	1	20111228-79034997
8				15	1	20110909-73626990
9				14	1	20110714-75328940
10				4	2	20080917-00125433

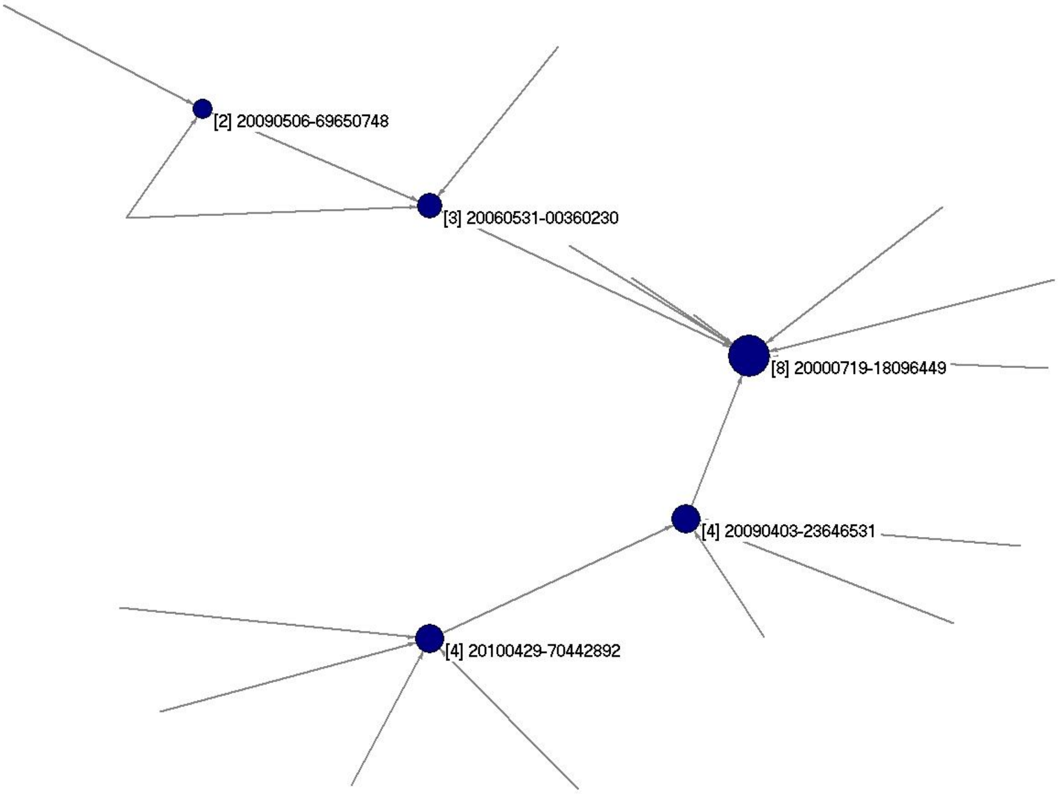

Figure 5.1.NP19. In-degree centrality of NP19

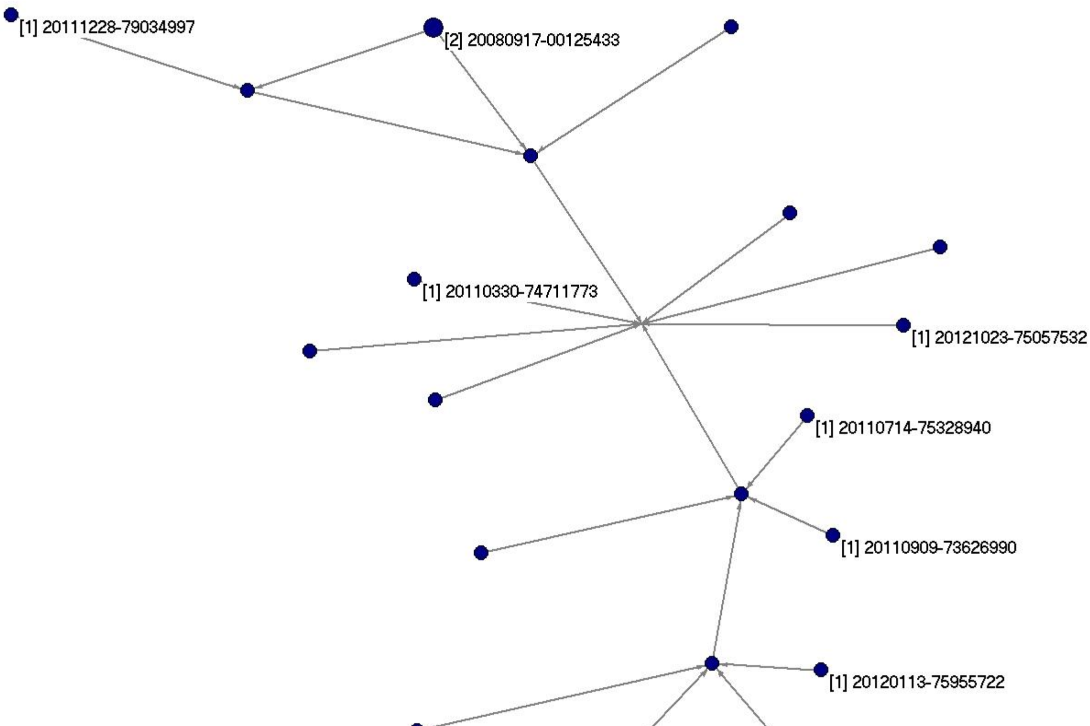

Figure 5.2.NP19. Out-degree centrality of NP19

Closeness centrality (Figure 5.3.NP19, Table 5.9.NP19) – P19 is the first among the top 10 patents according to the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP19, which shows P19 lying at the centre of the surrounding clusters.

Table 5.9.NP19. Top 10 closeness centrality values of NP19

Rank	Vertex	Value	Id (Label)
1	1 (P19)	0.54	20000719-18096449
2	5	0.50	20090403-23646531
3	3	0.41	20060531-00360230
4	11	0.39	20100429-70442892
5	6	0.35	20090409-68832306
6	13	0.35	20110330-74711773
7	2	0.35	20050909-29535678
8	21	0.35	20121023-75057532
9	9	0.35	20100218-71182337
10	8	0.35	20100217-00106452

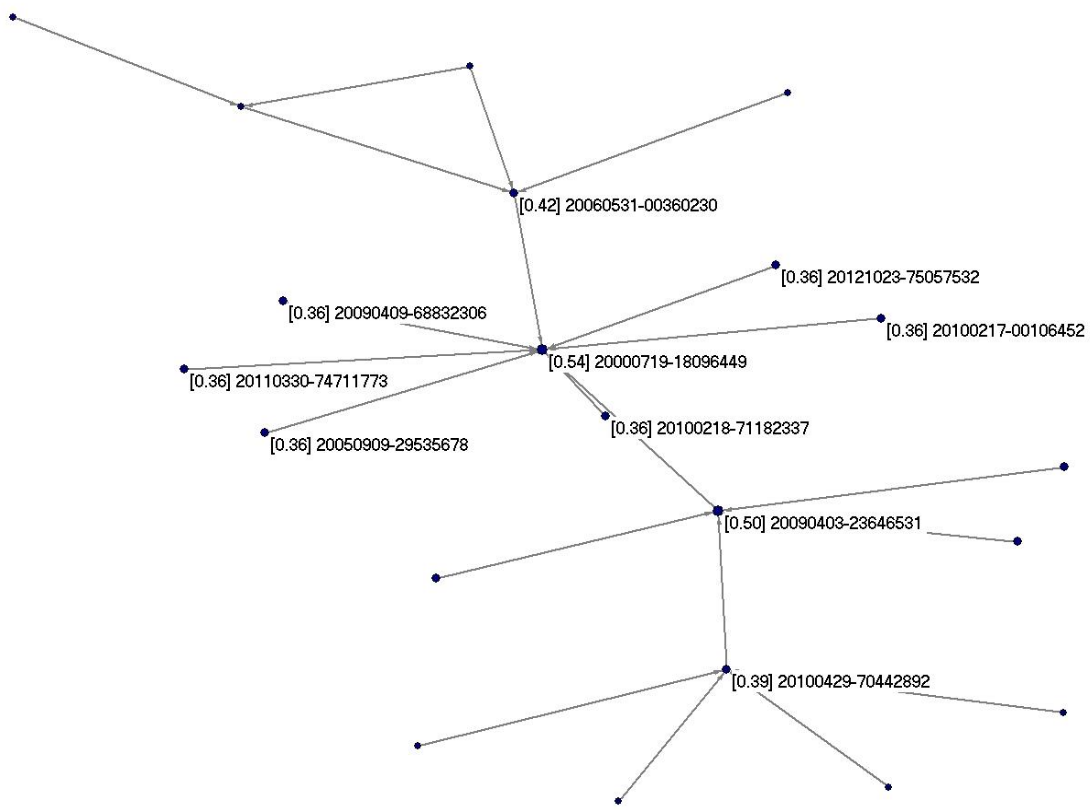

Figure 5.3.NP19. Closeness centrality of NP19

<u>Authority weights (Figure 5.4.NP19, Table 5.10.NP19)</u> – P19 is the only authority patent within NP19.

Table 5.10.NP19. The authority patent of NP19

Rank	Vertex	Value	Id (Label)
1	1 (P19)	1	20000719-18096449

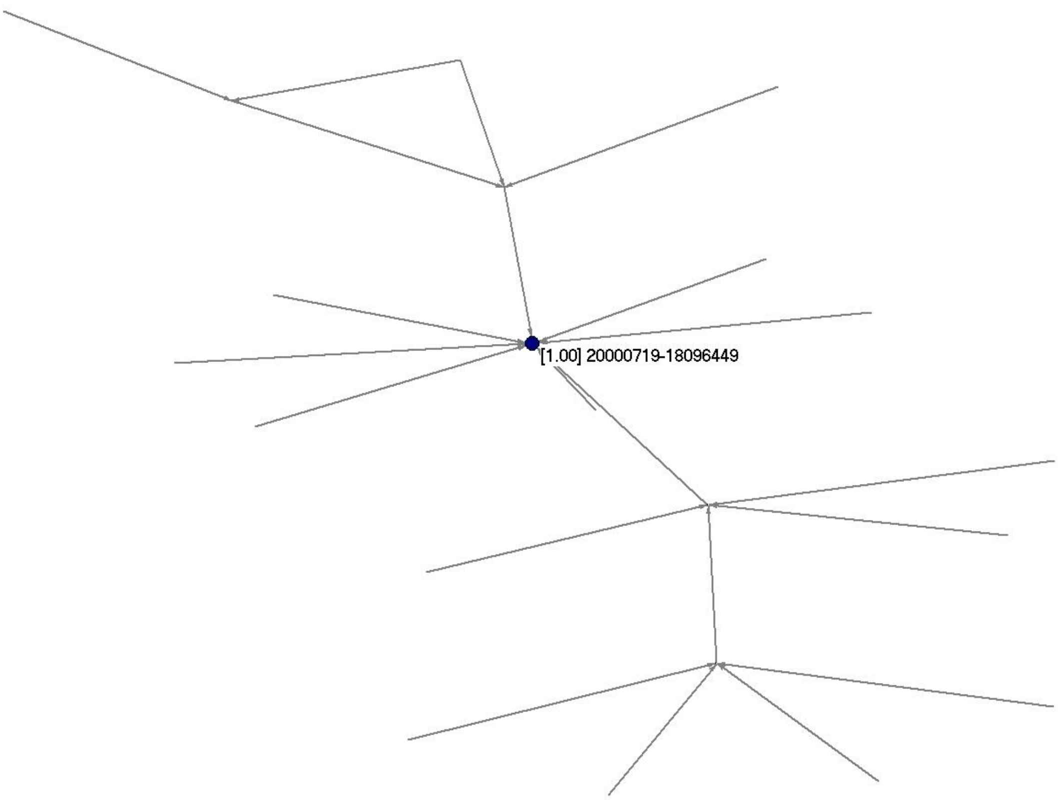

Figure 5.4.NP19. The authority patent of NP19

<u>Hub weights (Figure 5.5.NP19, Table 5.12.NP19)</u> – There are eight hubs within NP19, all with the same value of 0.35. The first five are:

- vertex 3, owned by the German company BBG GmbH & Co., with the title 'Wall panel for building with solar generator'.

- vertex 6, owned by a French inventor, with the title 'Device for holding photovoltaic panels on a roof, including holding means allowing an air flow between a base plane and the photovoltaic panel';
- vertex 13, owned by the British company Solion Ltd, with the title 'Mounting for solar panel';
- vertex 2, owned by a Greek inventor, with the title 'Shaping of a profile, frame or other structural element for the support of structural glazing with photovoltaic elements or for the support of other active and passive elements, suitable to incorporate and connect electrical or electronic sub-units';
- vertex 5, which has been described as the 2nd most cited patent in NP19.

Table 5.12.NP19. The hub patents of NP19

Rank	Vertex	Value	Id (Label)
1	3	0.35	20060531-00360230
2	6	0.35	20090409-68832306
3	13	0.35	20110330-74711773
4	2	0.35	20050909-29535678
5	5	0.35	20090403-23646531
6	21	0.35	20121023-75057532
7	9	0.35	20100218-71182337
8	8	0.35	20100217-00106452

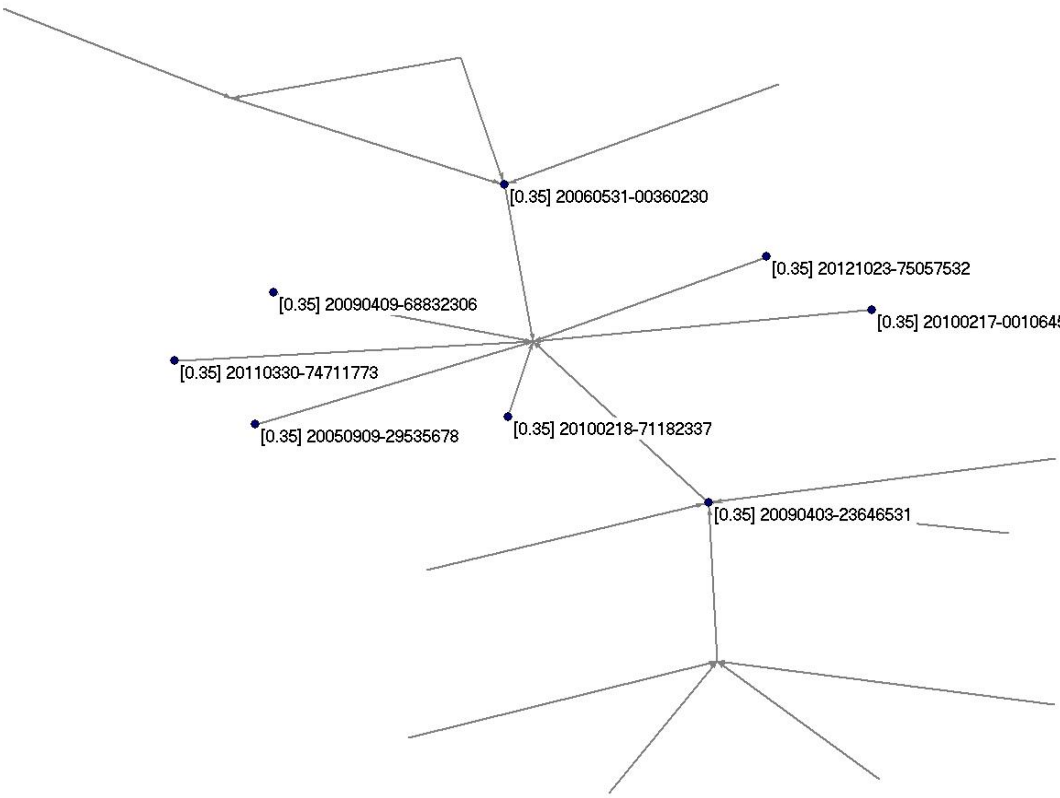

Figure 5.5.NP19. The hub patents of NP19

<u>*SPC (Figure 5.6.NP19, Table 5.12.NP19)*</u> – The 21 patents in NP19 are all part of its technological trajectory. This goes from P19 to the most recent patent (vertex 20), owned by two French inventors, with the title 'Device for ventilating space defined under photovoltaic panels in inclined roof of e.g. private building, has upper portion connected to front portion via articulated connections that allow angular clearance between front and upper portions'. Figure 5.6.NP19 clearly shows two focal points along the trajectory, the first is P19, and the second is vertex 5, which has been described as the 2nd most cited patent.

Table 5.12.NP19. Vertices on main path SPC [flow] of NP19

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000719-18096449
2	2	1	20050909-29535678
3	3	1	20060531-00360230

4	4	1	20080917-00125433
5	5	1	20090403-23646531
6	6	1	20090409-68832306
7	7	1	20090506-69650748
8	8	1	20100217-00106452
9	9	1	20100218-71182337
10	10	1	20100218-71327282
11	11	1	20100429-70442892
12	12	1	20101111-73573799
13	13	1	20110330-74711773
14	14	1	20110714-75328940
15	15	1	20110909-73626990
16	16	1	20111228-79034997
17	17	1	20120113-75955722
18	18	1	20120409-75523870
19	19	1	20120412-77730794
20	20	1	20120706-76247060
21	21	1	20121023-75057532

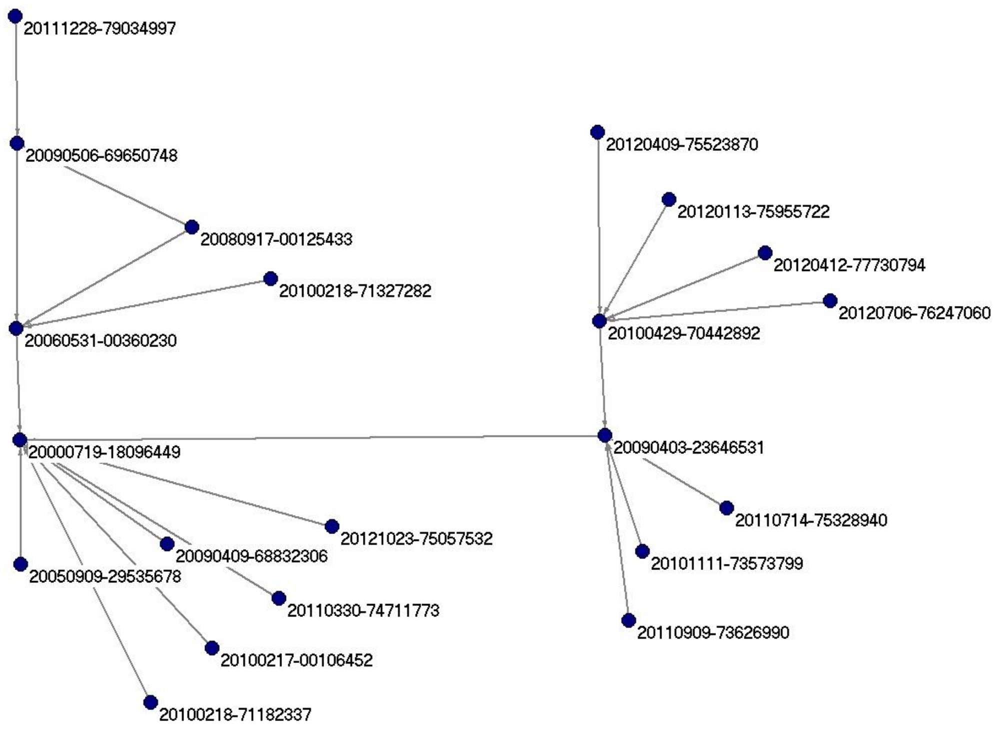

Figure 5.6.NP19. SPC of NP19

<u>Network and connectivity analysis of network built on P20 (NP20)- 20000823-18129885</u>

P20 is the European patent owned by the French company Clipsol with the title 'Process for mounting solar collector panels' (IPC: E04D3/06; F24J2/04). NP20 characteristics are given in Table 5.7.NP20.

Table 5.7.NP20. Characteristics

Number of vertices (n)	**13**
	Arcs
Total number of lines	12
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.07
Average degree	1.87

<u>*In-degree centrality (Figure 5.1.NP20, Table 5.8.NP20)*</u> - P20 is the 3rd most cited patent in NP20, the 1st most cited being vertex 2, owned by the German company Gehrlicher Solar, with the title 'Fastening structure for a large solar module, and solar module'.

Table 5.8.NP20. In-degree and out-degree centrality values of NP20

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	2	6	20100121-71087740	3	1	20100825-72040793
2	4	4	20110303-74917639	13	1	20121206-81222313
3	1 (P20)	2	20000823-18129885	12	1	20121123-77046314
4				11	1	20121121-77113180
5				10	1	20121107-77100973
6				9	1	20121019-77046234
7				8	1	20120830-80448938
8				7	1	20111121-78777240
9				6	1	20111117-76389334
10				5	1	20111019-73299629

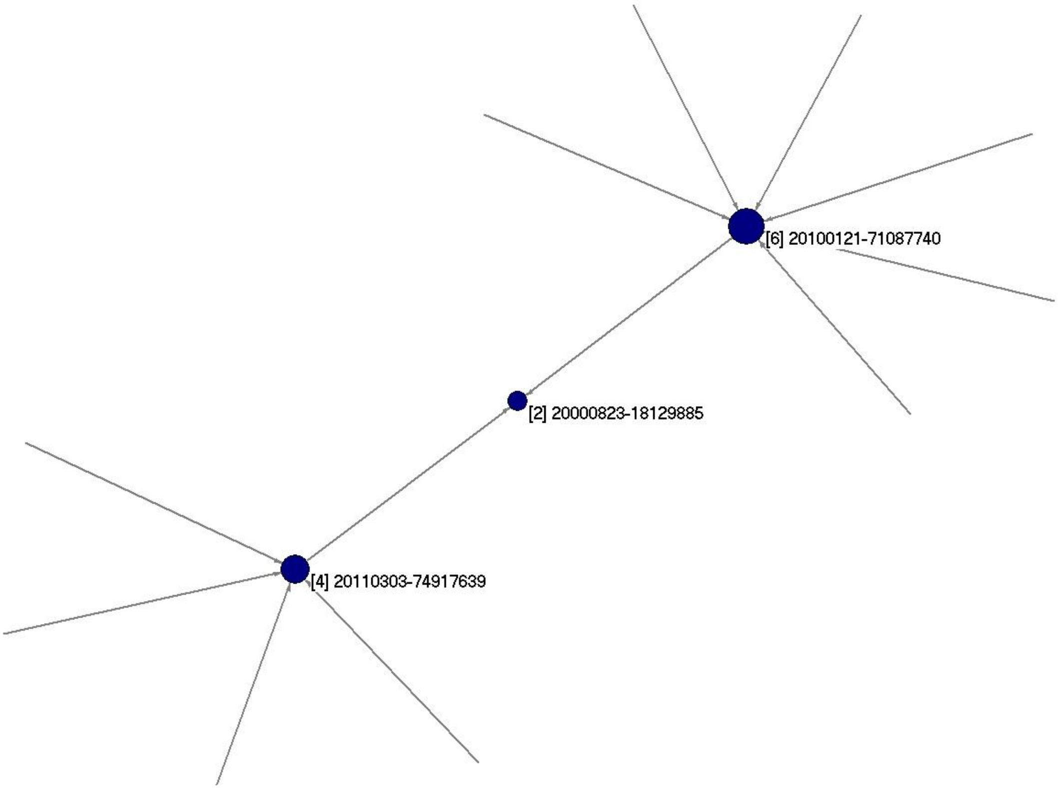

Figure 5.1.NP20. In-degree centrality of NP20

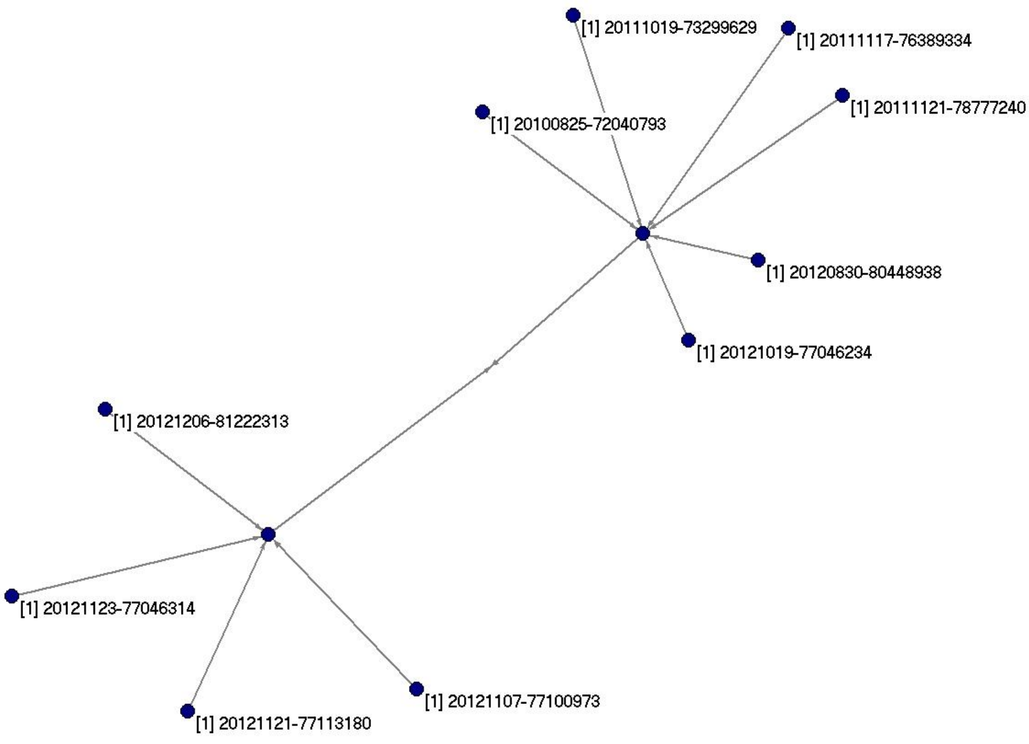

Figure 5.2.NP20. Out-degree of NP20

<u>*Closeness centrality (Figure 5.3.NP20, Table 5.9.NP20*</u>) – P20 is the 2nd among the top 10 patents according to the closeness centrality measure, with a value of 0.55. This means that it is near to the centre of local clusters and is relatively close to all the others. The patent ranked 1st, with a value of 0.57, is vertex 2, which has been described as the most cited. The concept is more intuitively explained by Figure 5.3.NP20, which shows the two patents lying at the centre of the surrounding clusters.

Table 5.9.NP20. Closeness centrality values of NP20

Rank	Vertex	Value	Id (Label)
1	2	0.57	20100121-71087740
2	1 (P20)	0.55	20000823-18129885
3	4	0.48	20110303-74917639
4	3	0.38	20100825-72040793
5	7	0.38	20111121-78777240
6	6	0.38	20111117-76389334
7	8	0.38	20120830-80448938
8	5	0.38	20111019-73299629
9	9	0.38	20121019-77046234
10	12	0.33	20121123-77046314

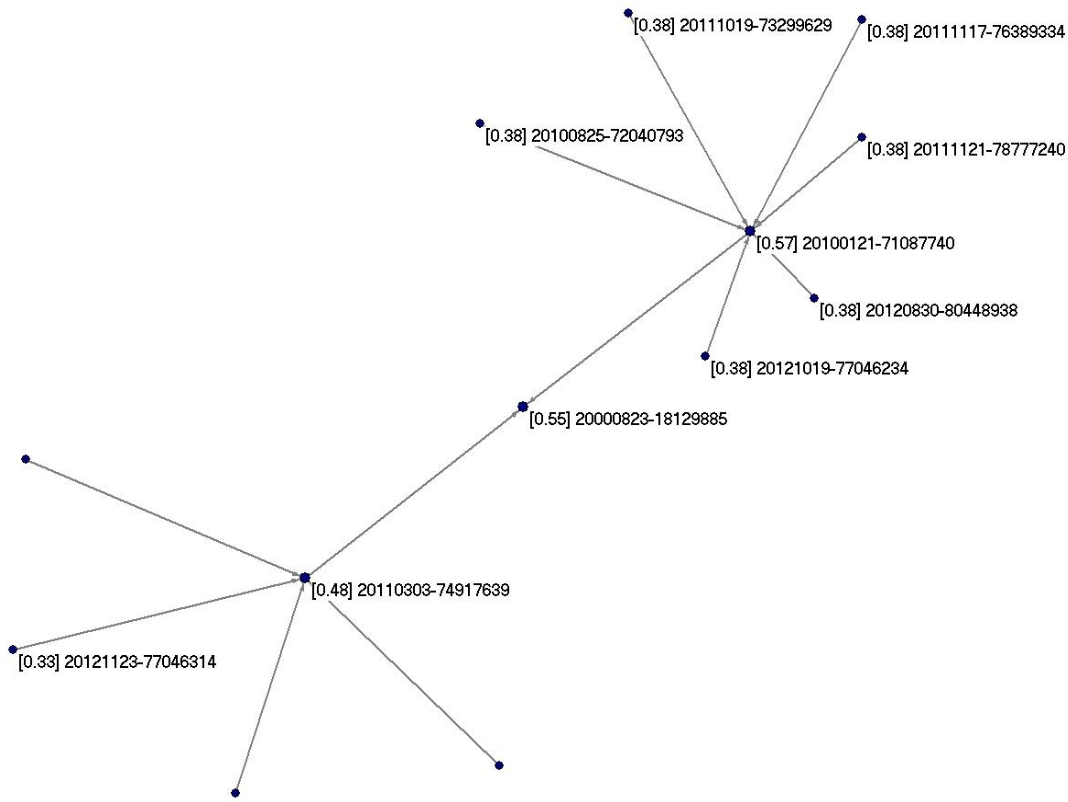

Figure 5.3.NP20. Closeness centrality of NP20

Authority weights (Figure 5.4.NP20, Table 5.10.NP20) – There are two authority patents. The first with the highest value is the most cited patent in NP20, the second (vertex 4) is a patent owned by the French company Actif Energy Vert, with the title 'Device for attaching at least one panel onto a supporting structure'.

Table 5.10.NP20. The authority patents of NP20

Rank	Vertex	Value	Id (Label)
1	2	1	20100121-71087740
2	4	0.02	20110303-74917639

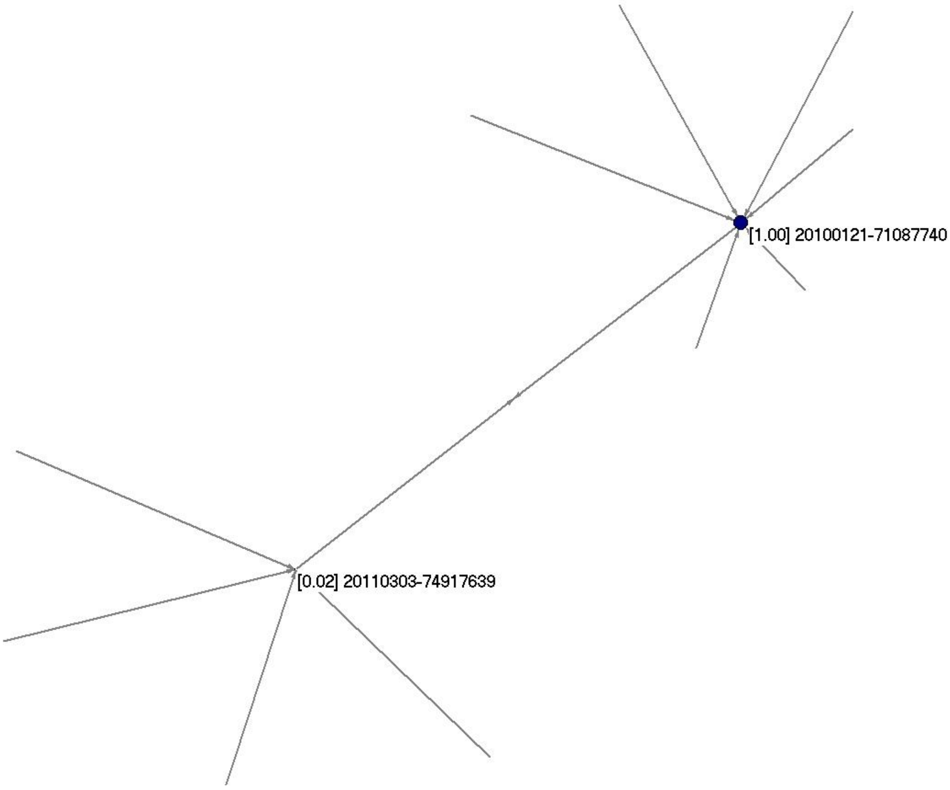

Figure 5.4.NP20. The authority patents of NP20

<u>*Hub weights (Figure 5.5.NP20, Table 5.11.NP20)*</u> – There are six hub patents in NP20, all with the same value. They represent the best developments of the first authority previously described.

- vertex 3, owned by the German company Climasol Solaranlagen GMBH, with the title 'Snap on connection';
- vertex 7, owned by a private inventor, with the title 'Montagesystem zur Aufdach, Fassaden, Flachdach und Freilandmontage von Photovoltaikmodulen oder Solarthermiekollektoren';
- vertex 6, owned by the company Sika Technologies, with the title 'Wedge-shaped carrier for solar cell';
- vertex 5, published in Europe by the company Sika Technologies, with the title 'Wedge-shaped carrier for solar cells';

- vertex 9, published in France by the French company Noelle Environment, with the title 'Mounting bracket for reception and fixing support section utilized for e.g. photovoltaic solar module of solar-powered heater on roof structure, has set of lateral reception extensions comprising support component extended in same plane'.

Table 5.11.NP20. The hub patents of NP20

Rank	Vertex	Value	Id (Label)
1	3	0.41	20100825-72040793
2	7	0.41	20111121-78777240
3	6	0.41	20111117-76389334
4	5	0.41	20111019-73299629
5	9	0.41	20121019-77046234
6	8	0.41	20120830-80448938

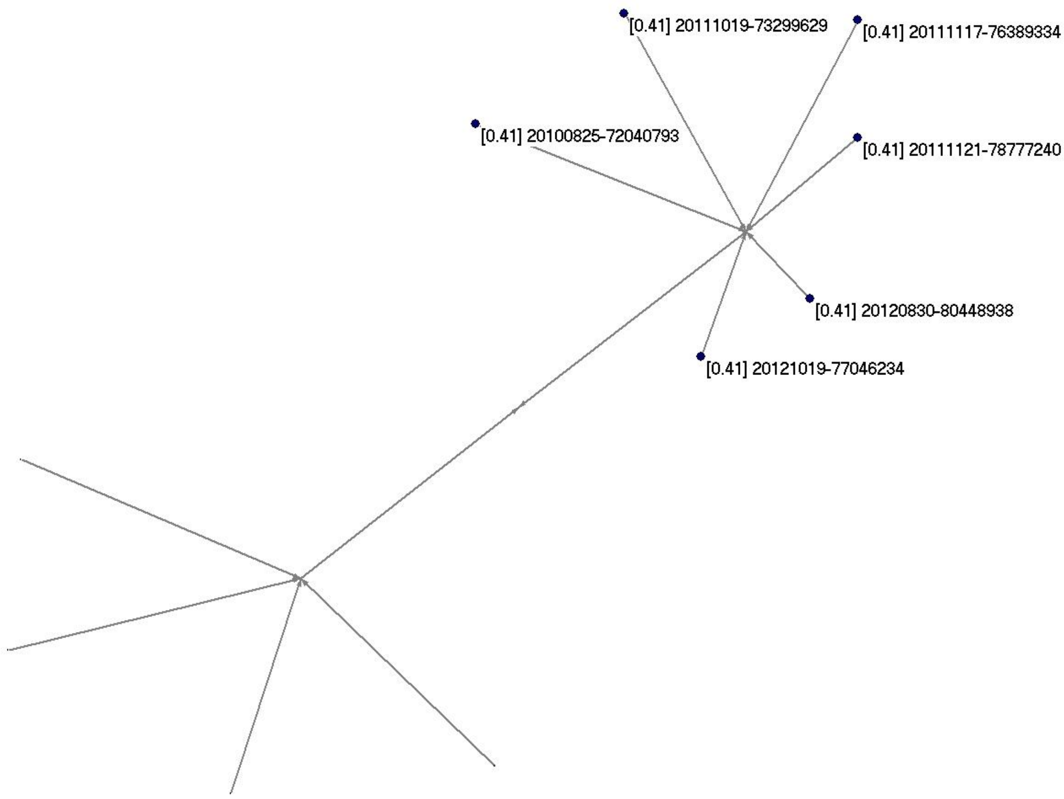

Figure 5.5.NP20. The hub patents of NP20

<u>*SPC (Figure 5.6.NP20, Table 5.12.NP20)*</u> – The 13 patents in NP20 belong to its technological trajectory. Figure 5.6.NP20 highlights three focal points. One is P20, another is vertex 2, which is also the most cited and the first authority in NP20, the third is vertex 4, which is also the second most cited and the second authority in NP20.

Table 5.12.NP20. Vertices of main path SPC [flow] of NP20

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000823-18129885
2	2	1	20100121-71087740
3	3	1	20100825-72040793
4	4	1	20110303-74917639
5	5	1	20111019-73299629
6	6	1	20111117-76389334
7	7	1	20111121-78777240
8	8	1	20120830-80448938
9	9	1	20121019-77046234
10	10	1	20121107-77100973
11	11	1	20121121-77113180
12	12	1	20121123-77046314
13	13	1	20121206-81222313

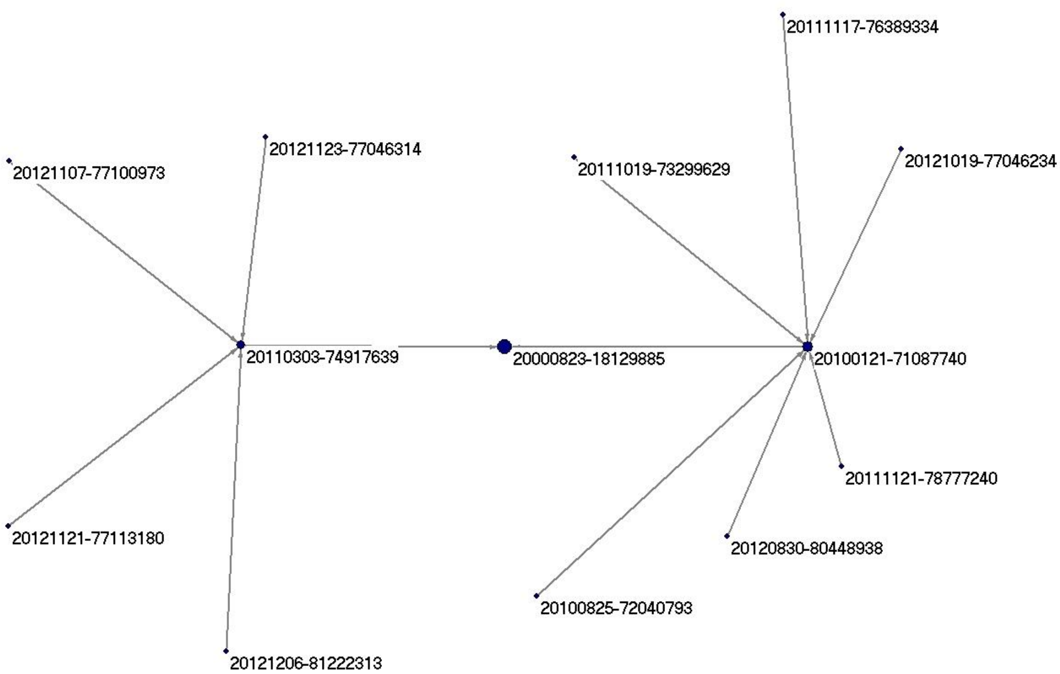

Figure 5.6.NP20. SPC of NP20

__Network and connectivity analysis of network built on P21 (NP21)- 20001025-18135927__

P21 is a European patent published by a private Sweden inventor with the title 'Burner with helicoidal path for combustion products'. NP21 characteristics are given in Table 5.8.NP21.

Table 5.7.NP21. Characteristics

Number of vertices (n)	**4**
	Arcs
Total number of lines	3
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.18
Average degree	1.50

__In-degree centrality (Figure 5.1.NP21, Table 5.8.NP21)__ – The most cited patent is vertex 2, which was published in Europe by the Danish company Biovarme, with the title 'A solid fuel burner unit and a method for cleaning the combustion chamber'. P21 is the second most cited patent in NP21.

Table 5.8.NP21. In-degree and out-degree centrality values of NP21

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	2	2	20071010-19087164	3	1	20101101-71719314
2	1(P21)	1	20001025-18135927	4	1	20110427-72582368
3				2	1	20071010-19087164

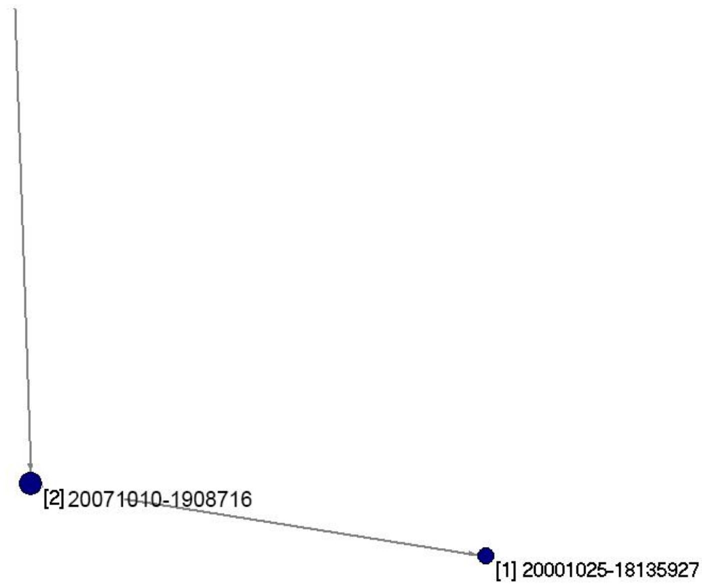

Figure 5.1.NP. In-degree centrality of NP21

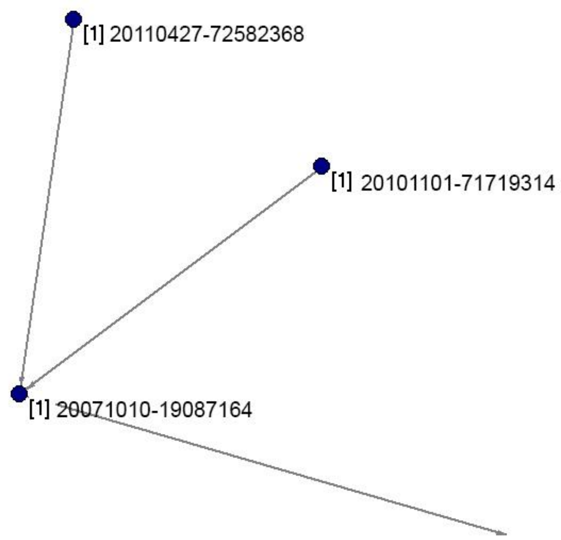

Figure 5.2.NP21. Out-degree centrality of NP21

<u>*Closeness centrality (Figure 5.3.NP21, Table 5.9.NP21)*</u> – According to the closeness centrality measure, the first patent is vertex 2, already described as the most cited (1st for in-degree

centrality). This means it is closest to the centre and to the others. The concept is more intuitively explained by Figure 5.3.NP21, which shows this patent lying at the centre of the surrounding clusters.

Table 5.9.NP21. Closeness centrality values of NP21

Rank	Vertex	Value	Id (Label)
1	2	1	20071010-19087164
2	4	0.60	20110427-72582368
3	3	0.60	20101101-71719314
4	1 (P21)	0.60	20001025-18135927

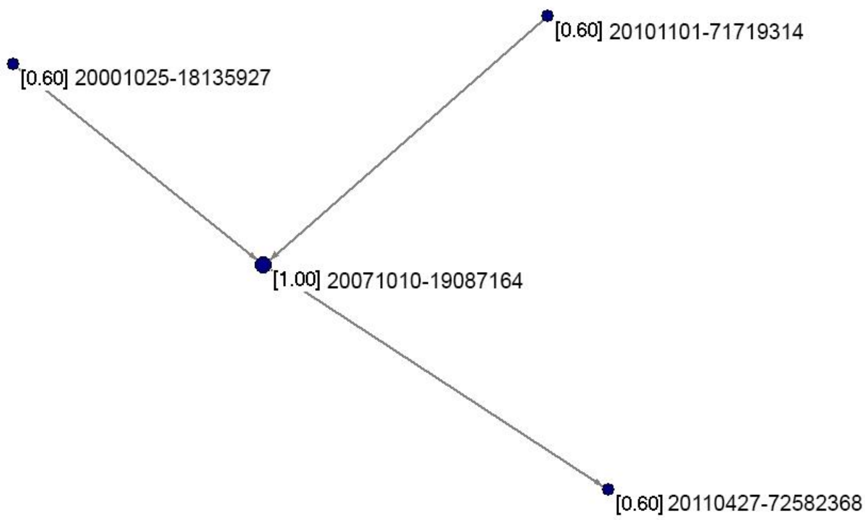

Figure 5.3.NP21. Closeness centrality of NP21

<u>*Authority weights (Figure 5.4.NP21, Table 5.10.NP21)*</u> – The only authority in NP21 is vertex 2, already described as the most cited (1st for in-degree centrality).

Table 5.10.NP21. The authority patent of NP21

Rank	Vertex	Value	Id (Label)
1	2	1	20071010-19087164

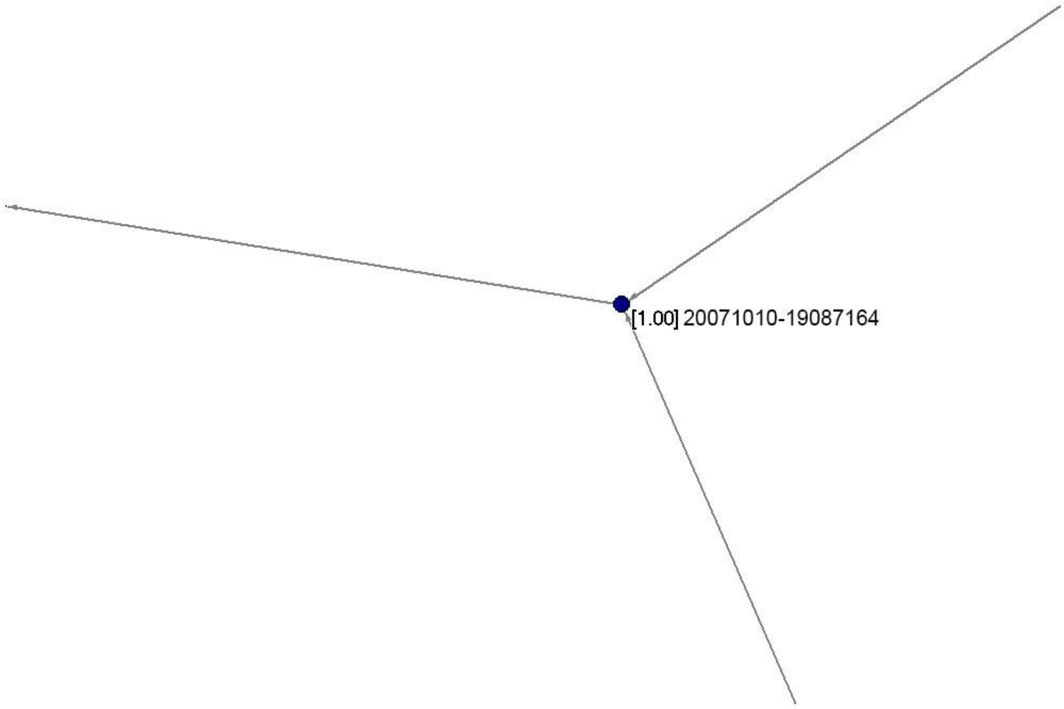

Figure 5.4.NP21. The authority patent of NP21

<u>*Hub weights (Figure 5.5.NP21, Table 5.11.NP21)*</u> – The two hub patents are:

- vertex 3, published in Italy by the Italian company Italforni, with the original language title 'Forno a combustibile solido';
- vertex 4, published in Italy by the Italian company Ecoteck, with the original language title 'Caldaia per il riscaldamento di edifice o ambienti similari'.

Table 5.11.NP21. The hub patents of NP21

Rank	**Vertex**	**Value**	**Id (Label)**
1	3	0.71	20101101-71719314
2	4	0.71	20110427-72582368

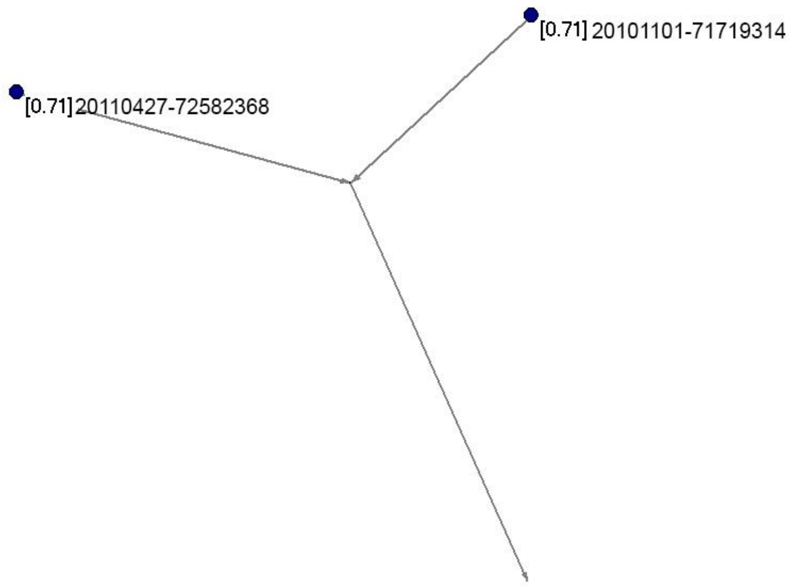

Figure 5.5.NP21. The hub patents of NP21

<u>*SPC (Figure 5.6.NP21, Table 5.12.NP21)*</u> – Figure 5.6.NP21 shows the technological trajectory of NP21, where P21 is followed by the authority patent vertex 2 which is the focal point from which the two hubs depart.

Table 5.12.NP21. Vertices on main path SPC [flow] of NP21

Rank	Vertex	Cluster	Id (Label)
1	1	1	20001025-18135927
2	2	1	20071010-19087164
3	3	1	20101101-71719314
4	4	1	20110427-72582368

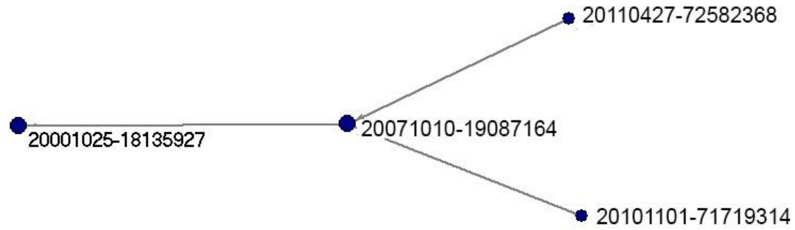

Figure 5.6.NP21. SPC of NP21

Network and connectivity analysis of network built on P22 (NP22)- 20011219-21050298

P22 is the European patent published by the Austrian Braun Union Osterreich, with the title 'Method for thermal utilization of spent grain' (IPC: F23G5/027). It is one of the few patents published in 2000 dealing with the renewable energy technology related to waste. NP22 characteristics are given in Table 5.7.NP22.

Table 5.7.NP22. Characteristics

Number of vertices (n)	**8**
	Arcs
Total number of lines	8
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.12
Average degree	2.00

In-degree centrality (Figure 5.1.NP22, Table 5.8.NP22) – P22 is the most cited patent in NP22. Followed by another two patents receiving one citation each.

Table 5.8.NP22. In-degree and out-degree centrality values of NP22

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	1 (P22)	6	20011219-21050298	5	2	20101202-74993913
2	3	1	20091231-71999985	8	1	20111117-76389280
3	2	1	20091223-70845760	7	1	20110421-76283261
4				6	1	20110309-74208859
5				3	1	20091231-71999985
6				4	1	20101124-73467272
7				2	1	20091223-70845760
8				5	2	20101202-74993913
9				8	1	20111117-76389280
10				7	1	20110421-76283261

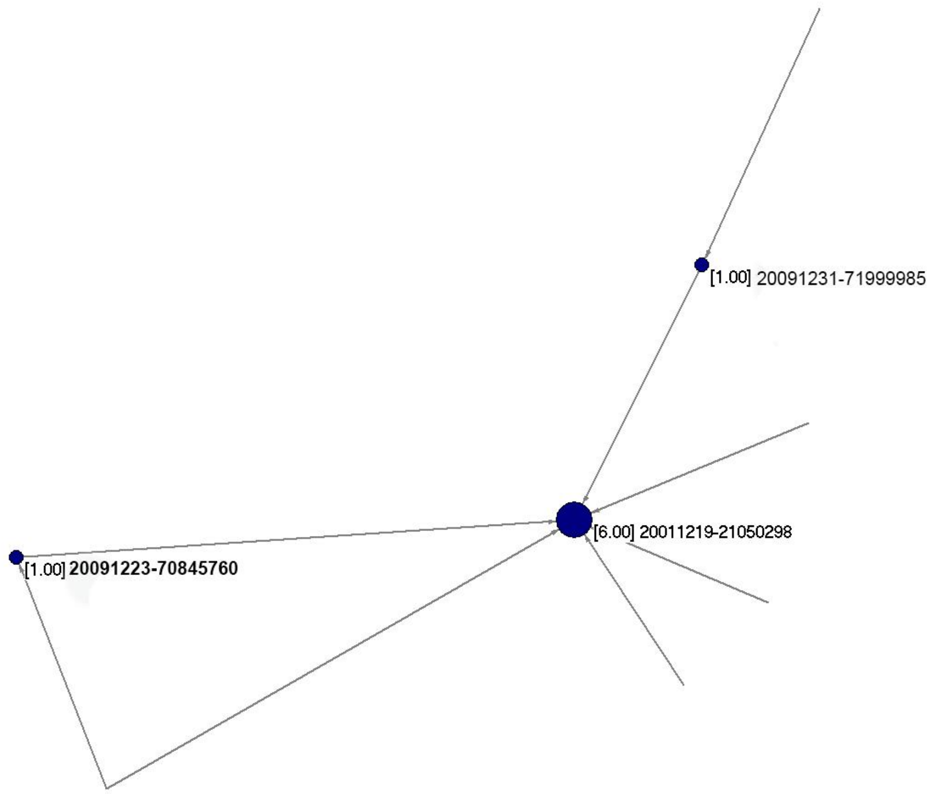

Figure 5.1.NP22. In-degree centrality of NP22

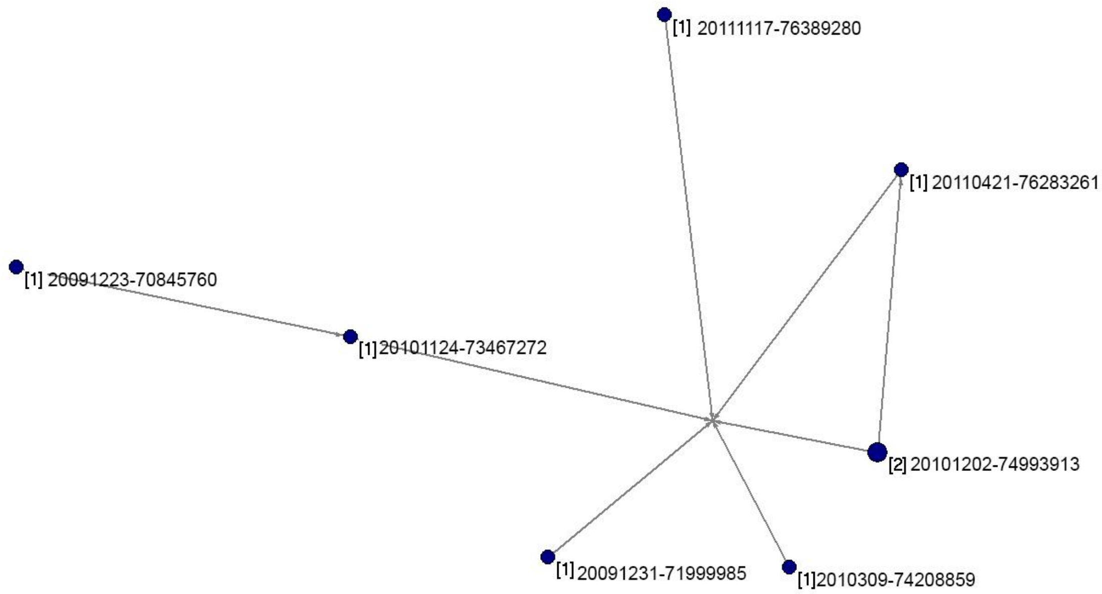

Figure 5.2.NP22. Out-degree centrality of NP22

Closeness centrality (Figure 5.3.NP22, Table 5.9.NP22) – P22 is the first among the top 10 patents according to the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP22 which shows P22 lying at the centre of the surrounding clusters.

Table 5.9.NP22. Closeness centrality values of NP22

Rank	Vertex	Value	Id (Label)
1	1 (P22)	0.88	20011219-21050298
2	2	0.58	20091223-70845760
3	3	0.54	20091231-71999985
4	5	0.54	20101202-74993913
5	7	0.50	20110421-76283261
6	4	0.50	20101124-73467272
7	6	0.50	20110309-74208859
8	8	0.39	20111117-76389280

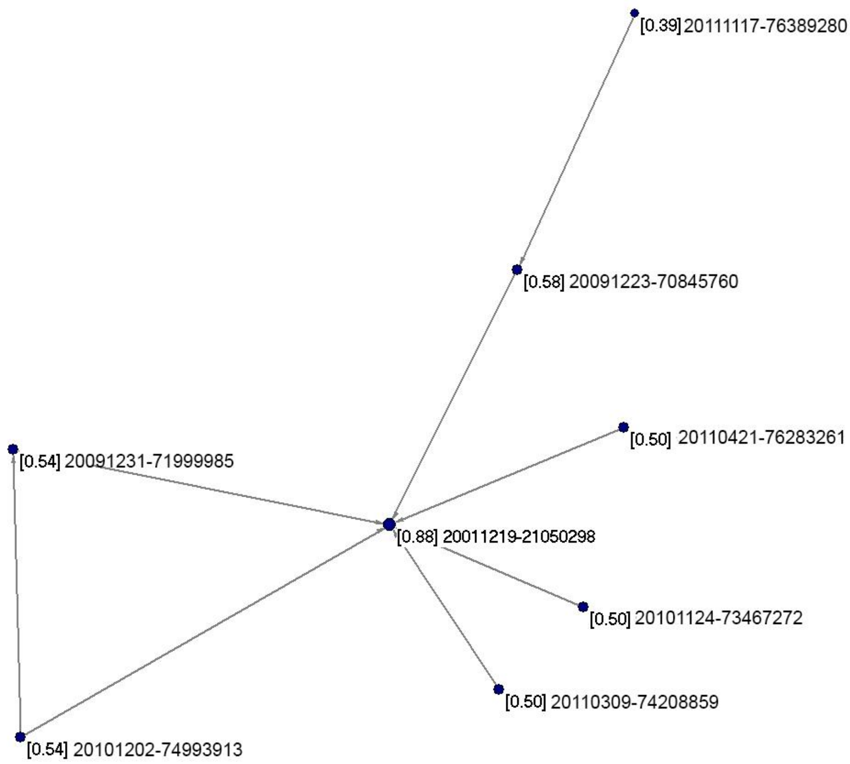

Figure 5.3.NP22. Closeness centrality of NP22

<u>*Authority weights (Figure 5.4.NP22, Table 5.10.NP22)*</u> – P22 is the most authority patent in NP22, followed by a second authority (vertex 3) which is the European patent published by the German GEA Brewery Systems GmbH, with the title 'Brewery installation with filtration device and for thermally using wet filtration particles'.

Table 5.10.NP22. The authority patents of NP22

Rank	**Vertex**	**Value**	**Id (Label)**
1	1 (P22)	0.98	20011219-21050298
2	3	0.19	20091231-71999985

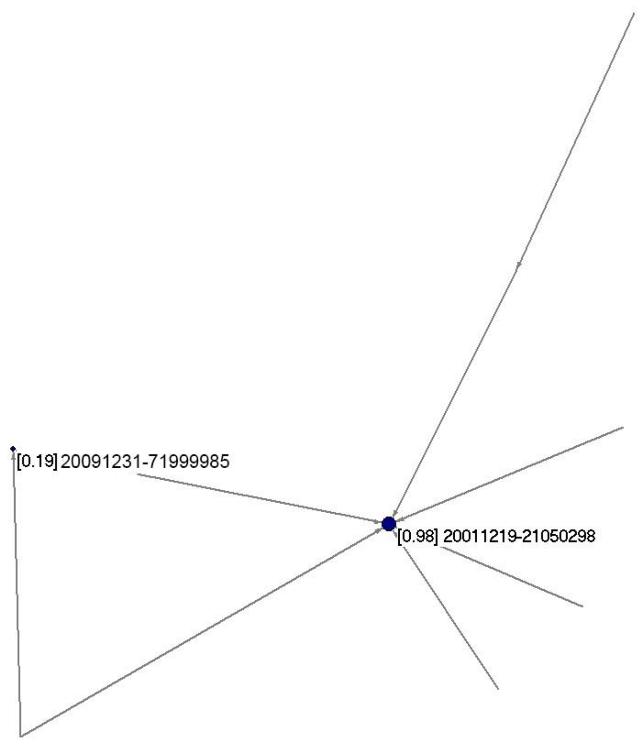

Figure 5.4.NP22. The authority patents of NP22

Hub weights (Figure 5.5.NP22, Table 5.11.NP22) – There are six hub patents in NP22. The first one, with a value of 0.47, is the European patent (vertex 5) published by the German company Ziemann Energy GmbH, with the title 'Method for treating residual materials in breweries'. The other five hubs obtained the same value (0.39).

Table 5.11.NP22. The hub patents of NP22

Rank	Vertex	Value	Id (Label)
1	5	0.47	20101202-74993913
2	3	0.39	20091231-71999985
3	7	0.39	20110421-76283261
4	6	0.39	20110309-74208859
5	2	0.39	20091223-70845760
6	4	0.39	20101124-73467272

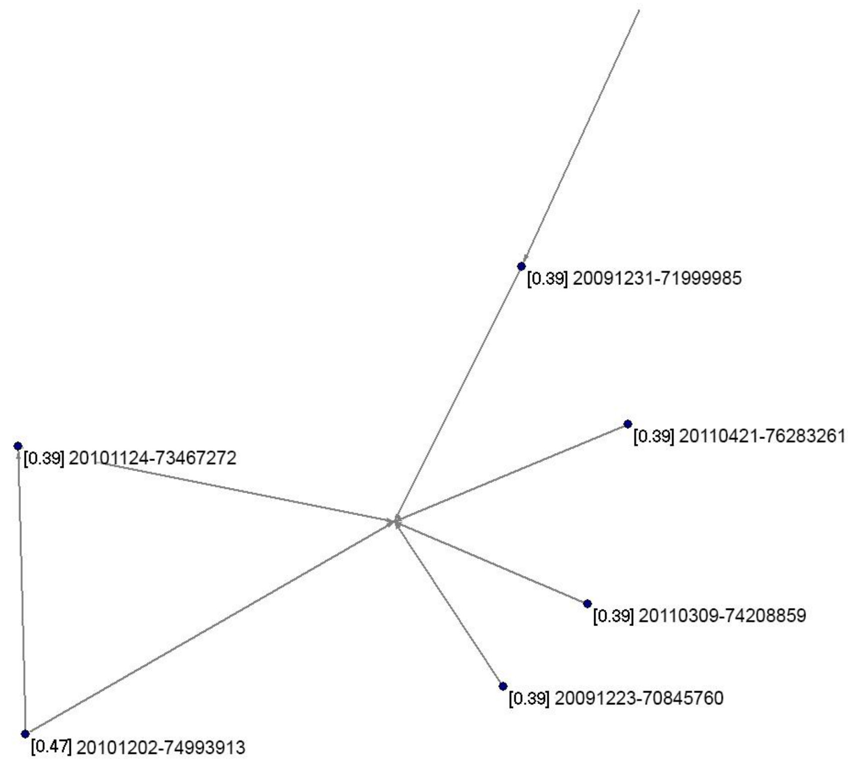

Figure 5.5.NP22. The hub patents of NP22

SPC (Figure 5.6.NP22, Table 5.12.NP22) – The technological trajectory of NP22 is characterized by all eight patents belonging to NP22.

Table 5.12.NP22. Vertices on main path SPC [flow] of NP22

Rank	Vertex	Cluster	Id (Label)
1	1	1	20011219-21050298
2	2	1	20091223-70845760
3	3	1	20091231-71999985
4	4	1	20101124-73467272
5	5	1	20101202-74993913
6	6	1	20110309-74208859
7	7	1	20110421-76283261
8	8	1	20111117-76389280

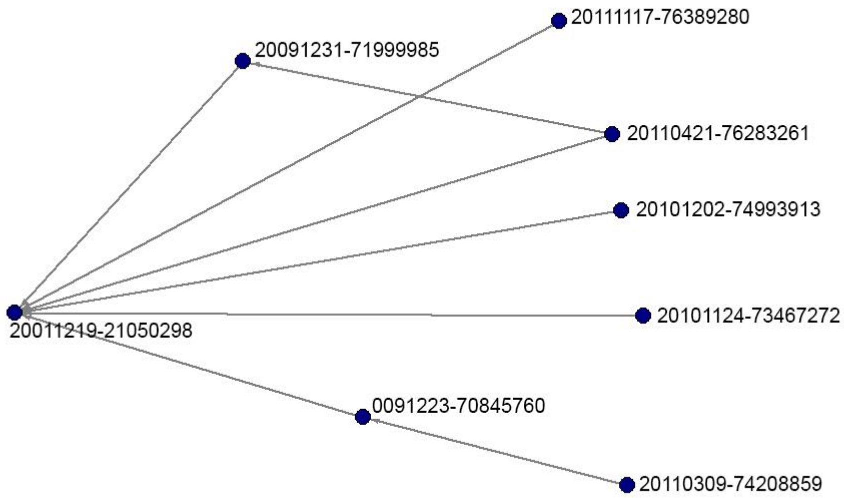

Figure 5.6.NP22. SPC of NP22

<u>Network and connectivity analysis of network built on P23 (NP23)- 20000614-21223243</u>

P23 is a European patent owned by the Japanese Kaneka Corporation, with the title 'Solar cell module' (IPC: H01L31/042). NP23 characteristics are given in Table 5.7.NP23.

Table 5.7.NP23. Characteristics

Number of vertices (n)	**14**
	Arcs
Total number of lines	13
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.06
Average degree	1.85

In-degree centrality (Figure 5.1.NP23, Table 5.8.NP23) – P23 is the 2nd most cited patent in NP23. The 1st most cited (vertex 2) with nine citations, is the European patent, owned by the Japanese Sharp Corporation, with the title 'Solar cell module edge face sealing member and solar cell module employing same'.

Table 5.8.NP23. In-degree and out-degree centrality values of NP23

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	2	9	20050629-18788353	3	1	20050901-49539133
2	1 (P23)	2	20000614-21223243	7	1	20100107-71152651
3	6	1	20091230-71228351	13	1	20121206-81339596
4	5	1	20091112-71184946	12	1	20121023-79026878
5				11	1	20120807-72194225
6				10	1	20120717-72194227
7				9	1	20120622-76987686
8				8	1	20120424-75934054
9				14	1	20121213-79430641
10				6	1	20091230-71228351

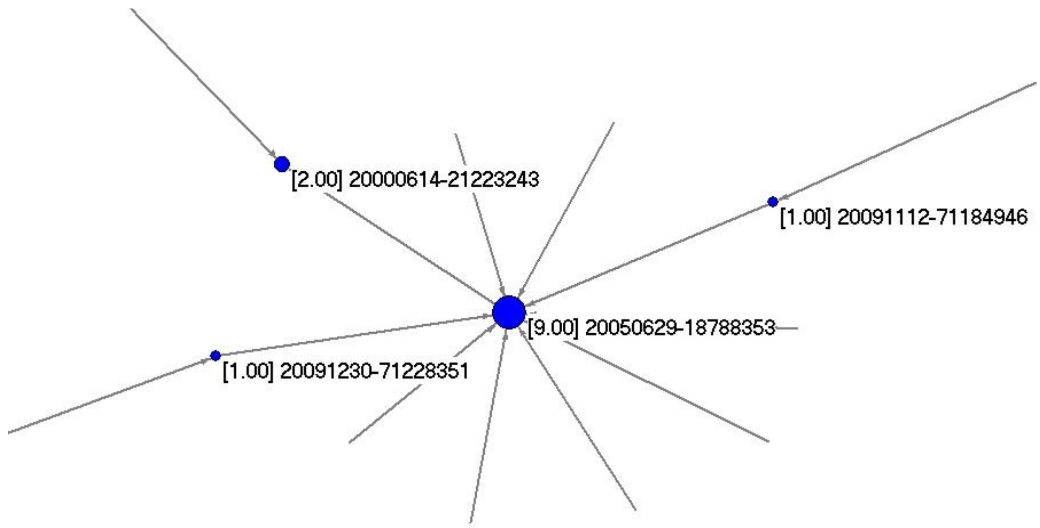

Figure 5.1.NP23. In-degree centrality of NP23

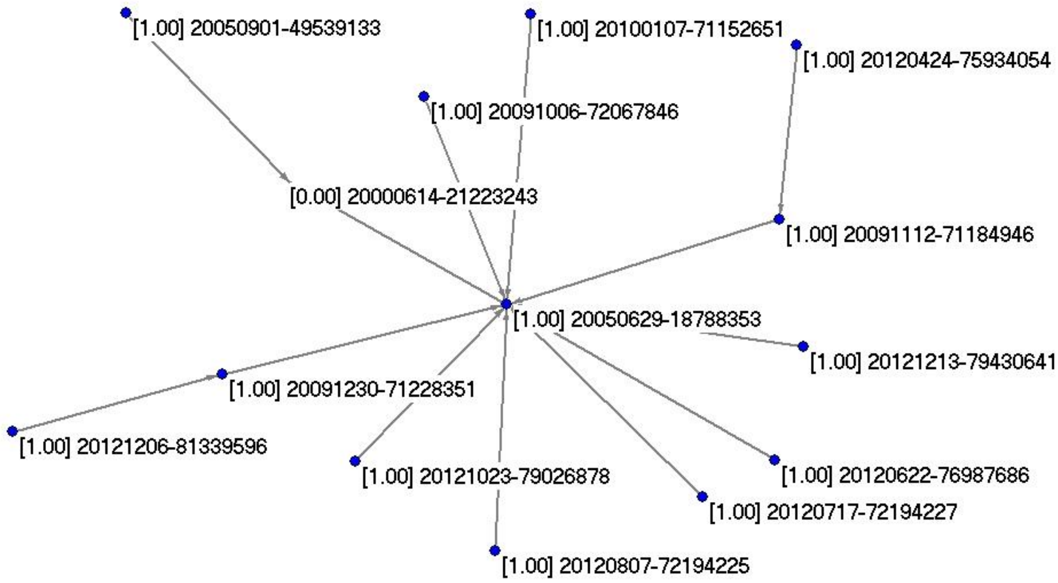

Figure 5.2.NP23. Out-degree centrality of NP23

<u>*Closeness centrality (Figure 5.3.NP23, Table 5.9.NP23)*</u> – P22 is 3rd among the top 10 patents according to the closeness centrality measure. The top ranked is vertex 2 already described. This means that this one is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP23 which shows vertex 2 lying at the centre of the surrounding clusters, with the highest value (0.81).

Table 5.9.NP23. Closeness centrality values of NP23

Rank	Vertex	Value	Id (Label)
1	2	0.81	20050629-18788353
2	6	0.50	20091230-71228351
3	1 (P22)	0.50	20000614-21223243
4	5	0.50	20091112-71184946
5	14	0.46	20121213-79430641
6	7	0.46	20100107-71152651
7	9	0.46	20120622-76987686
8	12	0.46	20121023-79026878

9	11	0.46	20120807-72194225
10	10	0.46	20120717-72194227

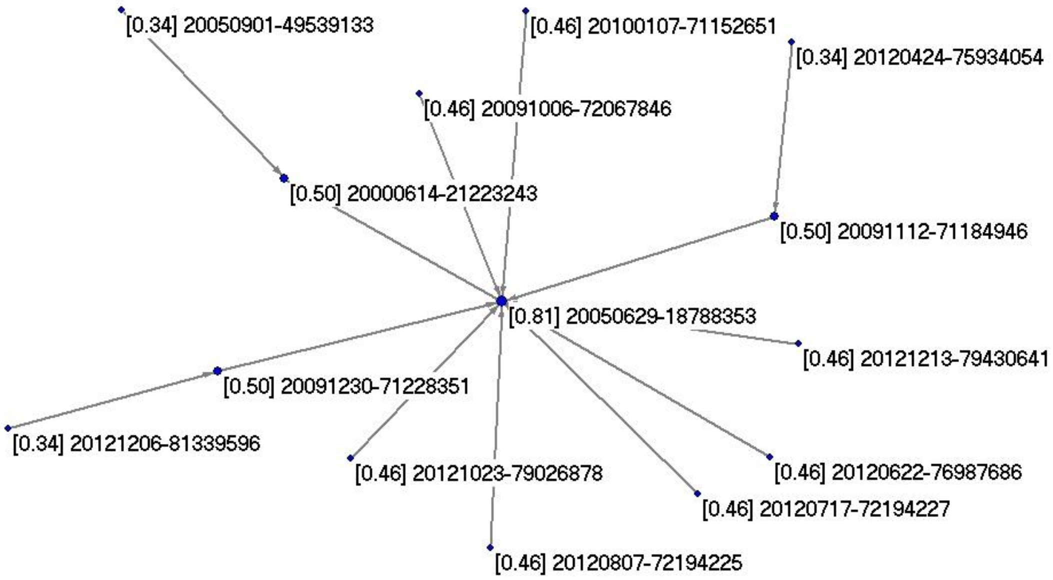

Figure 5.3.NP23. Closeness centrality of NP23

<u>*Authority weights (Figure 5.6.NP23, Table 5.10.NP23)*</u> – There is only one authority patent along NP23, which is the most cited patent, vertex 2.

Table 5.10.NP23. The authority patent of NP23

Rank	Vertex	Value	Id (Label)
1	2	1	20050629-18788353

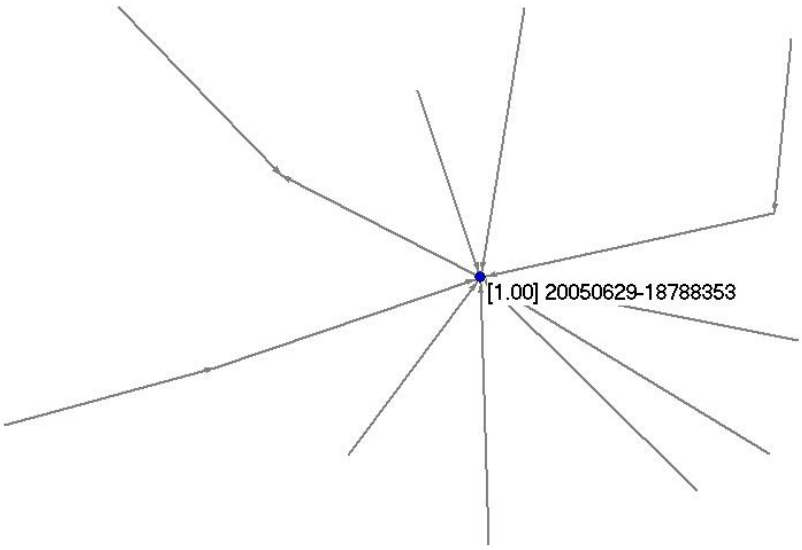

Figure 5.4.NP23. The authority patent of NP23

Hub weights (Figure 5.5.NP23, Table 5.11.NP23) – There are nine best developments of the NP23 authority and all obtained the same value of 0.33. As expected, they were published later than the authority, between 2009 and 2012. The first (vertex 7) is the patent owned by the Belgian company Saint Gobain Performance Plastics, Polymer Solutions, with the title 'Framed device, seal, and method for manufacturing same'.

Table 5.11.NP23. The hub patents of NP23

Rank	Vertex	Value	Id (Label)
1	7	0.33	20100107-71152651
2	14	0.33	20121213-79430641
3	6	0.33	20091230-71228351
4	12	0.33	20121023-79026878
5	5	0.33	20091112-71184946
6	11	0.33	20120807-72194225
7	9	0.33	20120622-76987686
8	10	0.33	20120717-72194227
9	4	0.33	20091006-72067846

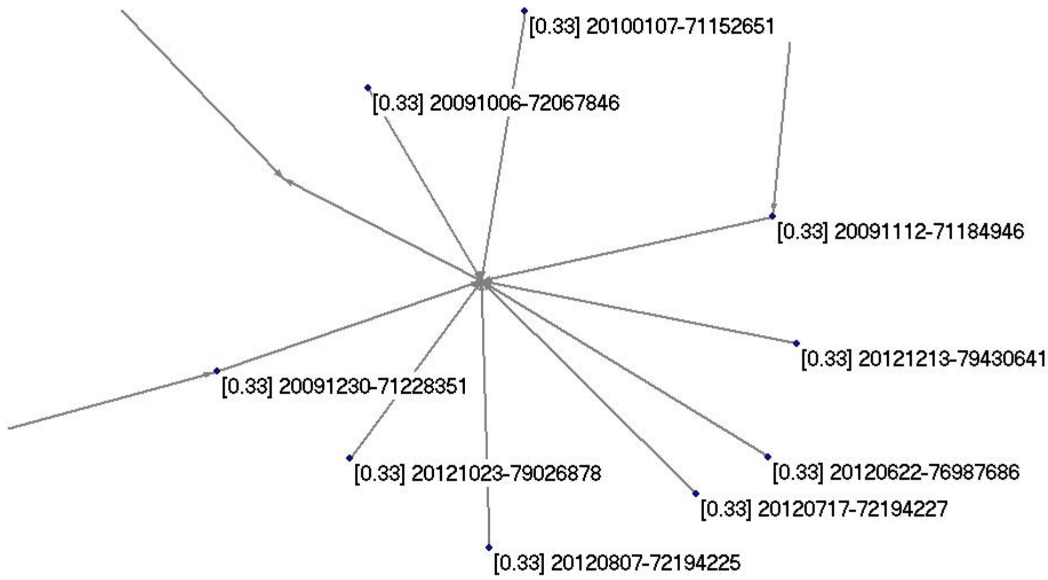

Figure 5.5.NP23. The hub patents of NP23

<u>*SPC (Figure 5.6.NP23, Table 5.12.NP23)*</u> – NP23 technological trajectory is characterized by its 14 patents. Figure 5.6.NP23 shows that it is possible to highlight a focal point, after publication of P23, from which many other patents develop. This is vertex 2, already described as the most cited and the highest authority patent.

Table 5.12.NP23. Vertices on main path SPC [flow] of NP23

Rank	**Vertex**	**Cluster**	**Id (Label)**
1	1	1	20000614-21223243
2	2	1	20050629-18788353
3	3	1	20050901-49539133
4	4	1	20091006-72067846
5	5	1	20091112-71184946
6	6	1	20091230-71228351
7	7	1	20100107-71152651
8	8	1	20120424-75934054
9	9	1	20120622-76987686
10	10	1	20120717-72194227
11	11	1	20120807-72194225
12	12	1	20121023-79026878

13	13	1	20121213-79430641
14	14	1	20121206-81339596

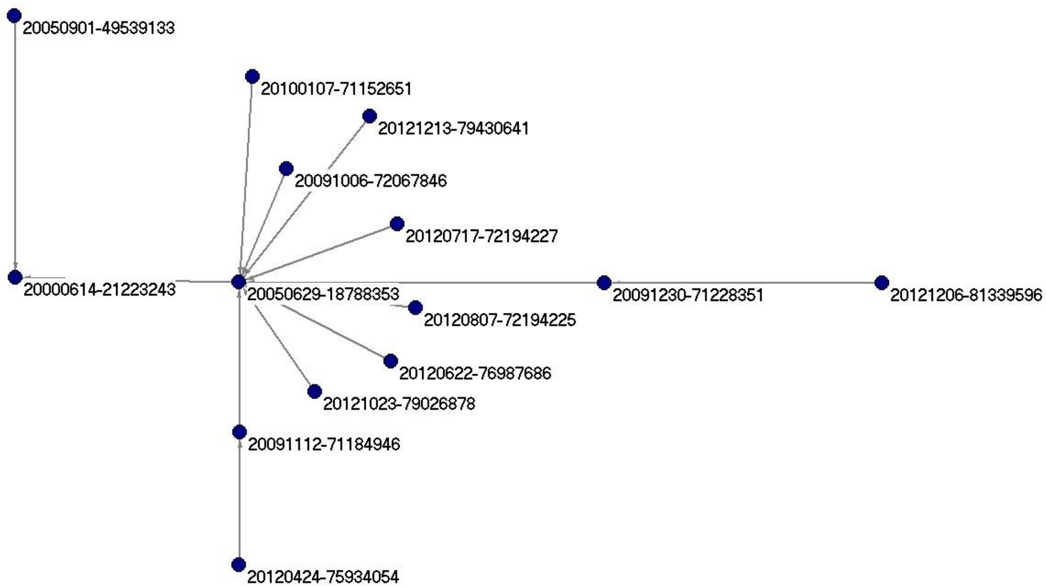

Figure 5.6.NP23. SPC of NP23

<u>Network and connectivity analysis of network built on P27 (NP27)- 20000927-21273202</u>

P27 is a European patent published by the German company Lafarge Braas Roofing Accessories GmbH, with the title 'Fastening system for a panel-shaped building element' (IPC: E04D13/18). NP27 characteristics are given in Table 5.7.NP27.

Table 5.7.NP27. Characteristics

Number of vertices (n)	**28**
	Arcs
Total number of lines	40
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.05
Average degree	2.85

<u>*In-degree centrality (Figure 5.1.NP27, Table 5.8.NP27)*</u> – P27 is the most cited patent in NP27, with a value of 9. A second patent (vertex 3) obtained the same value for in-degree centrality, the European owned by the Japanese Sharp KK Corporation, with the title 'Solar cell module edge face sealing member and solar cell module employing same'.

Table 5.8.NP27. In-degree and out-degree centrality values of NP27

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	1 (P27)	9	20000927-21273202	3	2	20050629-18788353
2	3	9	20050629-18788353	19	2	20120622-76987686
3	10	6	20100120-00043096	27	1	20121213-80035154
4	2	3	20040512-18620201	26	1	20121213-79430641
5	7	1	20091112-71184946	25	1	20121206-81339596
6	8	1	20091230-71228351	24	1	20121023-79026878
7				23	1	20120824-77099740
8				22	1	20120822-79108233
9				21	1	20120807-72194225
10				20	1	20120717-72194227

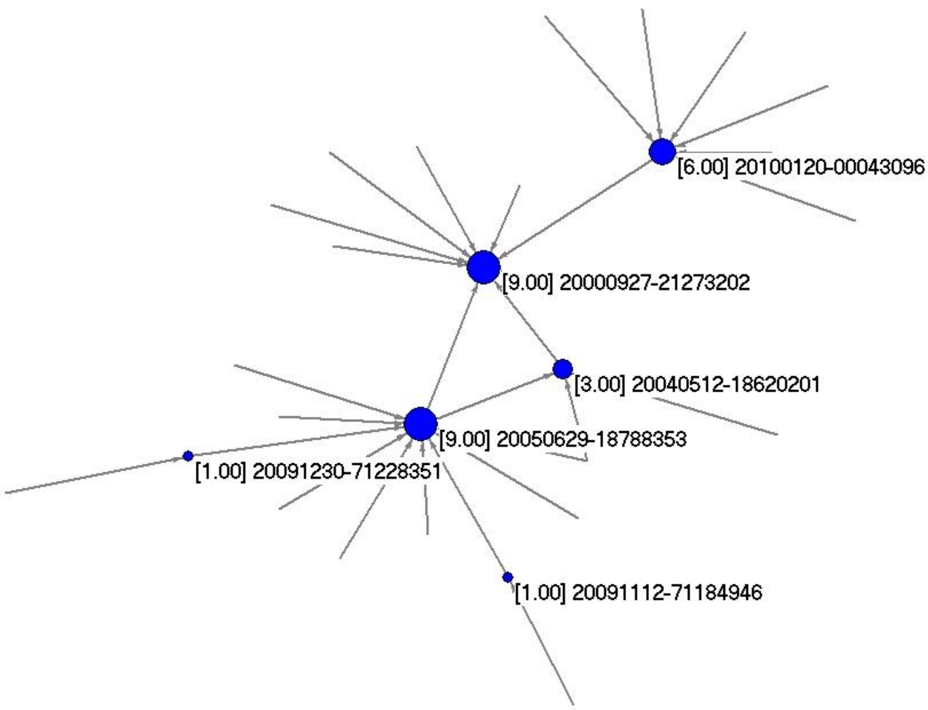

Figure 5.1.NP27. In-degree centrality of NP27

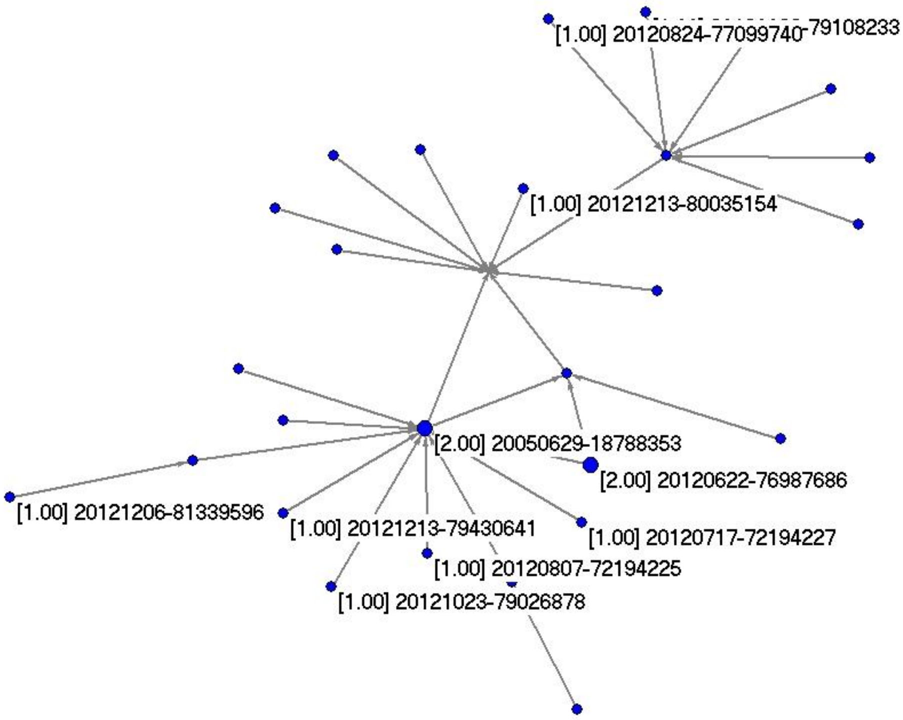

Figure 5.2.NP27. Out-degree centrality of NP27

<u>*Closeness centrality (Figure 5.3.NP27, Table 5.9.NP27)*</u> - P27 is the first among the top 10 patents according to the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP27 which shows P27 lying at the centre of the surrounding clusters.

Table 5.9.NP27. Closeness centrality values of NP27

Rank	Vertex	Value	Id (Label)
1	1 (P27)	0.57	20000927-21273202
2	3	0.55	20050629-18788353
3	2	0.47	20040512-18620201
4	19	0.44	20100120-00043096
5	7	0.37	20091112-71184946
6	28	0.37	20121214-79185010
7	13	0.37	20110428-75074355
8	27	0.37	20121213-80035154
9	5	0.37	20070502-19142454
10	4	0.37	20060515-01408144

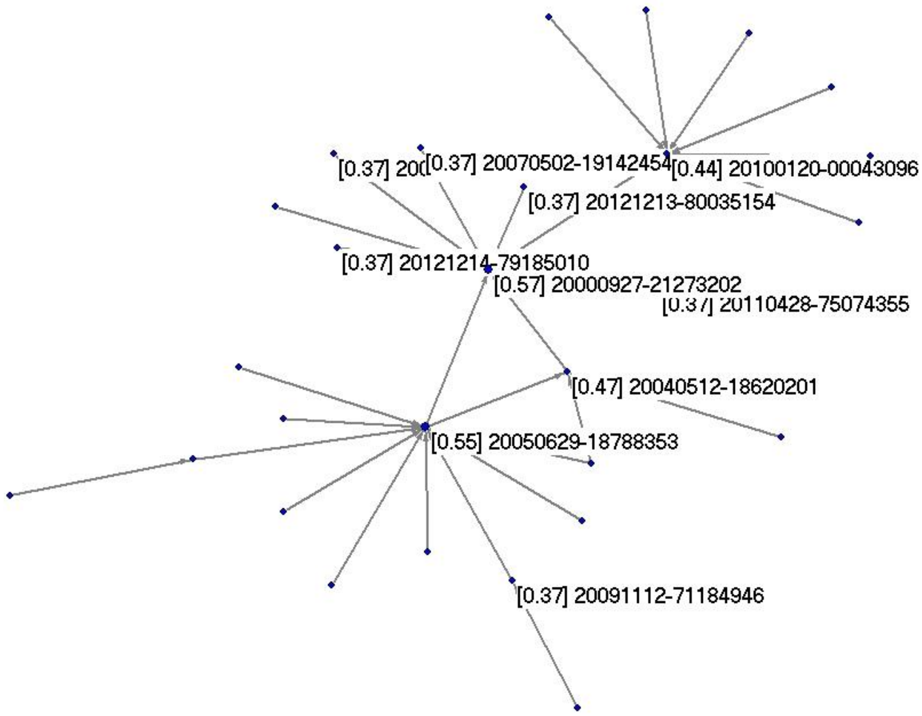

Figure 5.3.NP27. Closeness centrality of NP27

Authority weights (Figure 5.4.NP27, Table 5.10.NP27) – There are two authority patents in NP27. The most important is vertex 3 already described as one of the most cited, the second authority, with a smaller value (0.06), is vertex 2, which is owned by the same company, the Japanese Sharp KK Corporation, with the title 'Solar cell module and edge face sealing member for same'.

Table 5.10.NP27. The authority patents of NP27

Rank	Vertex	Value	Id (Label)
1	3	1	20050629-18788353
2	2	0.06	20040512-18620201

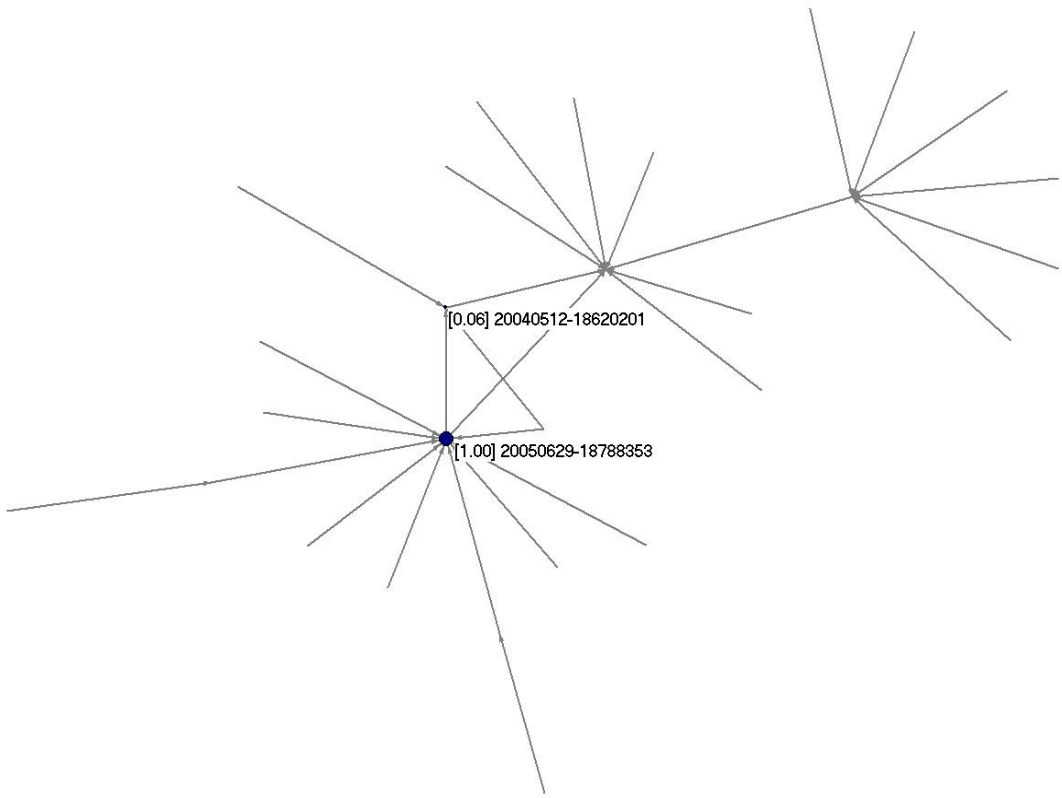

Figure 5.4.NP27. The authority patents of NP27

Hub weights (Figure 5.5.NP27, Table 5.11.NP27) – There are 10 hub patents in NP27. The most important, with a value of 0.34, is vertex 19, the European owned by two French inventors, with the title 'Device for supporting photovoltaic panel in e.g. roof, has intermediate strips for covering each of edges of panel, where intermediate strips are shaped to cooperate with groove in interlocking manner'.

Table 5.11.NP27. The hub patents of NP27

Rank	Vertex	Value	Id (Label)
1	19	0.34	20120622-76987686
2	7	0.33	20091112-71184946
3	6	0.33	20091006-72067846
4	26	0.33	20121213-79430641
5	24	0.33	20121023-79026878
6	21	0.33	20120807-72194225
7	20	0.33	20120717-72194227
8	9	0.33	20100107-71152651
9	8	0.33	20091230-71228351

10	3	0.01	20050629-18788353

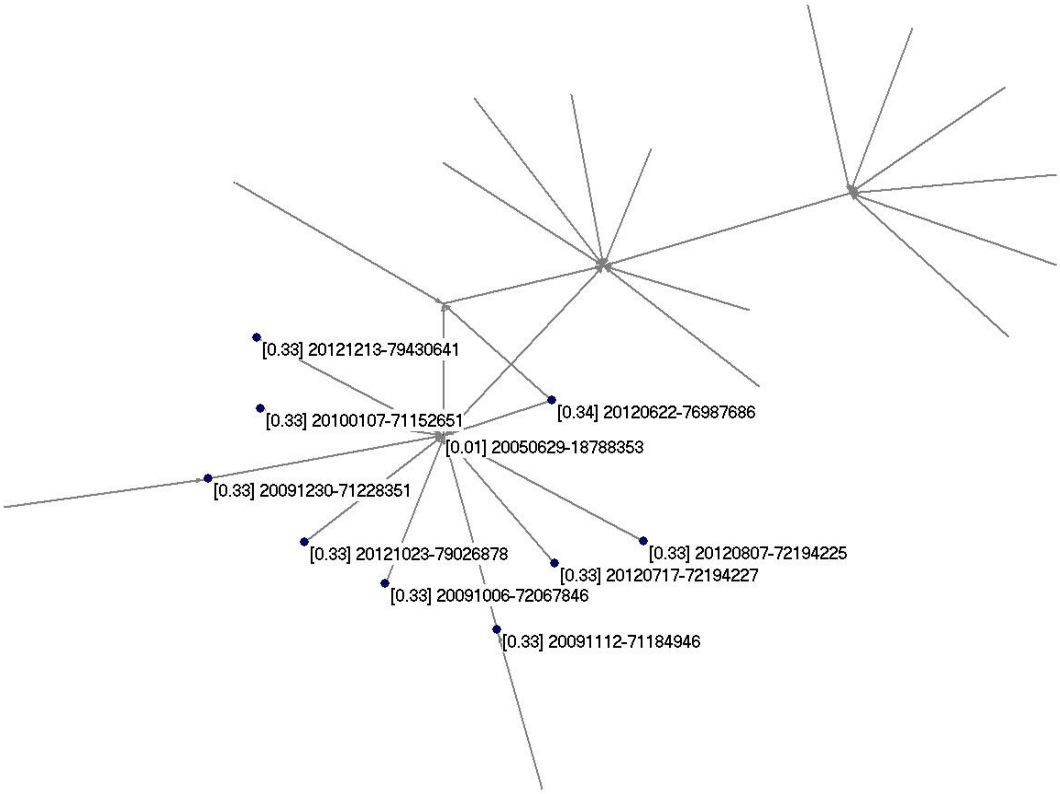

Figure 5.5.NP27. The hub patents of NP27

<u>*SPC (Figure 5.6.NP27, Table 5.12.NP27)*</u> – Figure 5.6.NP27 shows the technological trajectory of NP27, as characterized by 14 patents. It departs from P27 and shows a focal point represented by vertex 3, which is also the highest authority patent in NP27.

Table 5.12.NP27. Vertices on main path SPC [flow] of NP27

Rank	**Vertex**	**Cluster**	**Id (Label)**
1	1	1	20000927-21273202
2	2	1	20040512-18620201
3	3	1	20050629-18788353
4	6	1	20091006-72067846
5	7	1	20091112-71184946
6	26	1	20121213-79430641
7	25	1	20121206-81339596
8	24	1	20121023-79026878
9	21	1	20120807-72194225
10	20	1	20120717-72194227
11	9	1	20100107-71152651

12	19	1	20120622-76987686
13	8	1	20091230-71228351
14	17	1	20120424-75934054

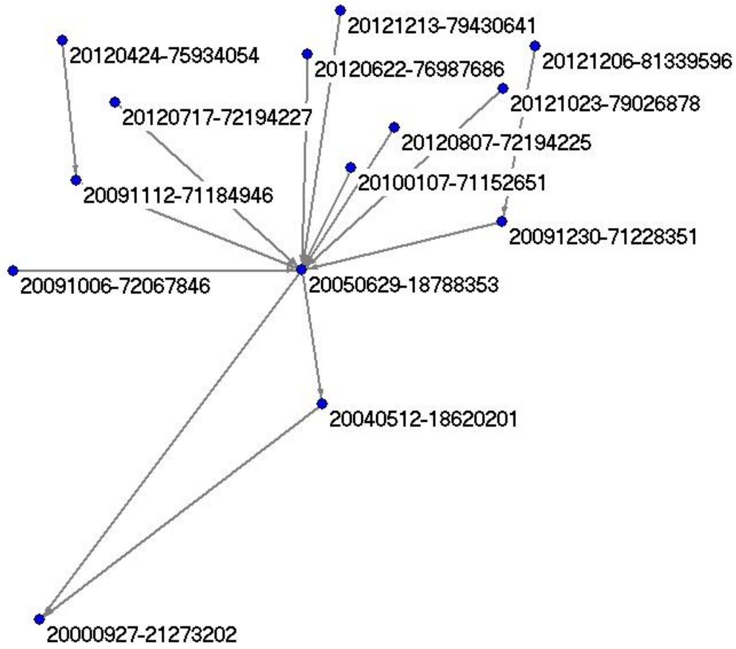

Figure 5.6.NP27. SPC of NP27

<u>Network and connectivity analysis of network built on P29 (NP29)- 20000112-21283820</u>

P29 is a European patent published by the Japanese Canon KK Corporation, with the title 'Photovoltaic element and production method therefor' (IPC: H01L27/142). NP29 characteristics are given in Table 5.7.NP29.

Table 5.7.NP29. Characteristics

Number of vertices (n)	**13**
	Arcs
Total number of lines	12
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.07
Average degree	1.84

In-degree centrality (Figure 5.1.NP29, Table 5.8.NP29) – P29 is the most cited patent in NP29, with a value of 4. The second most cited is vertex 3 obtaining three citations; it is a European patent owned by the French company Apollon Solar, with the title 'Photovoltaic module production, with photovoltaic cells between glass substrates, in which the positive and negative linkage conductors are provided by gluing copper strips to one glass substrate'.

Table 5.8.NP29. In-degree and out-degree centrality values of NP29

Rank	In-degree centrality			Out-degree centrality		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	1 (P29)	4	20000112-21283820	3	1	20040730-23526077
2	3	3	20040730-23526077	13	1	20130110-79910788
3	2	2	20030703-57930898	12	1	20120426-77905977
4	5	2	20060309-49566360	11	1	20110721-77173450
5	4	1	20040902-25975338	10	1	20101202-17075730
6				9	1	20100407-68660604
7				8	1	20090701-69582896
8				7	1	20090423-70046679
9				6	1	20071220-50714402
10				5	1	20060309-49566360

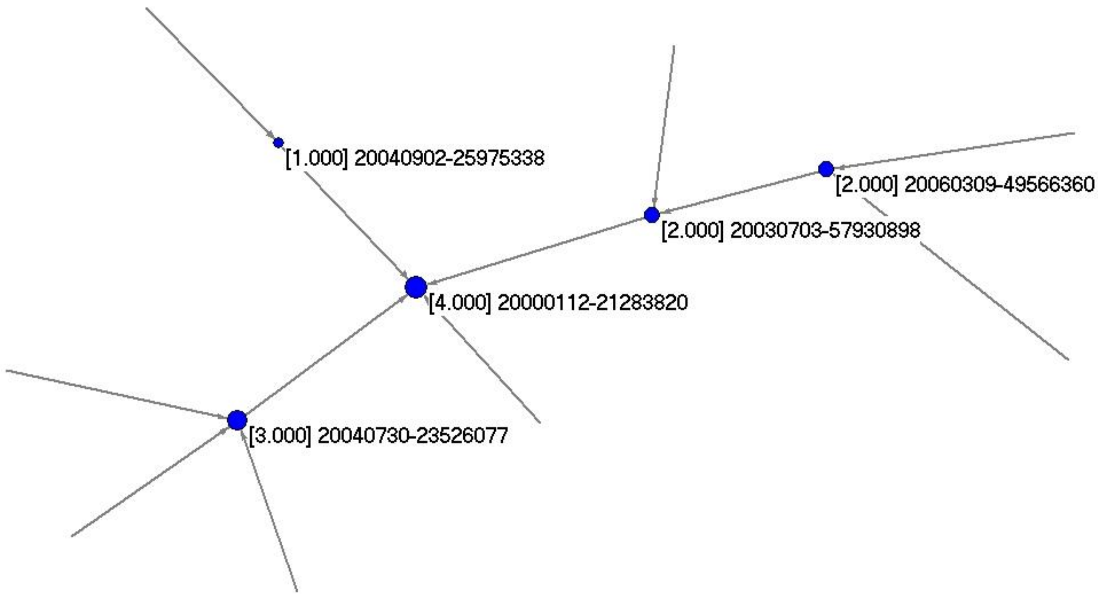

Figure 5.1.NP29. In-degree centrality of NP29

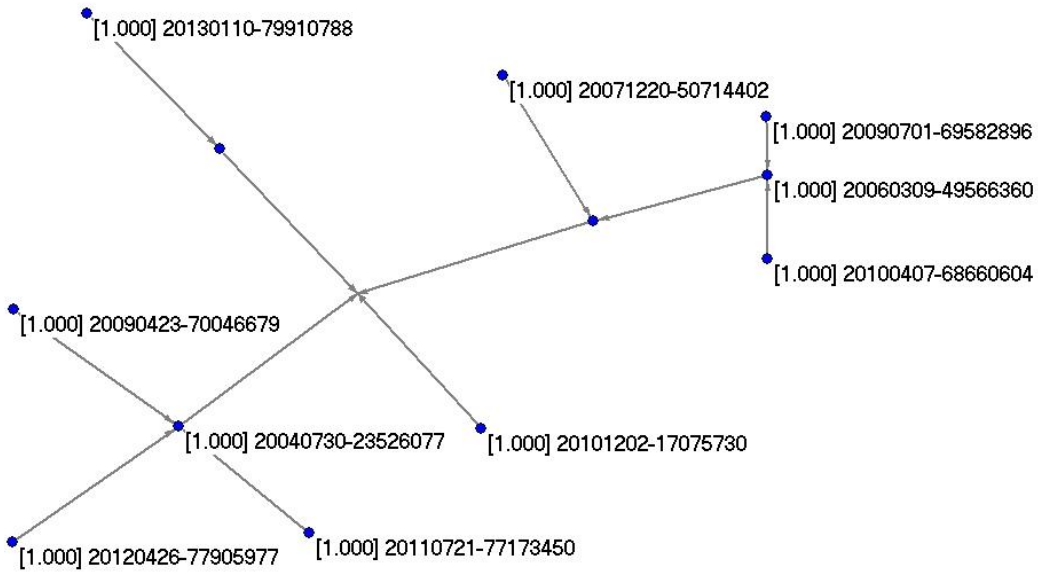

Figure 5.2.NP29. Out-degree centrality of NP29

<u>*Closeness centrality (Figure 5.3.NP29, Table 5.9.NP29)*</u> – P29 is ranked 1st in the top 10 patents according to the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP29, which shows P29 lying at the centre of the surrounding clusters.

Table 5.9.NP29. Closeness centrality values of NP29

Rank	Vertex	Value	Id (Label)
1	1 (P29)	0.55	20000112-21283820
2	2	0.48	20030703-57930898
3	3	0.44	20040730-23526077
4	4	0.39	20040902-25975338
5	5	0.38	20060309-49566360
6	10	0.36	20101202-17075730
7	6	0.33	20071220-50714402
8	7	0.32	20090423-70046679
9	12	0.32	20120426-77905977
10	11	0.32	20110721-77173450

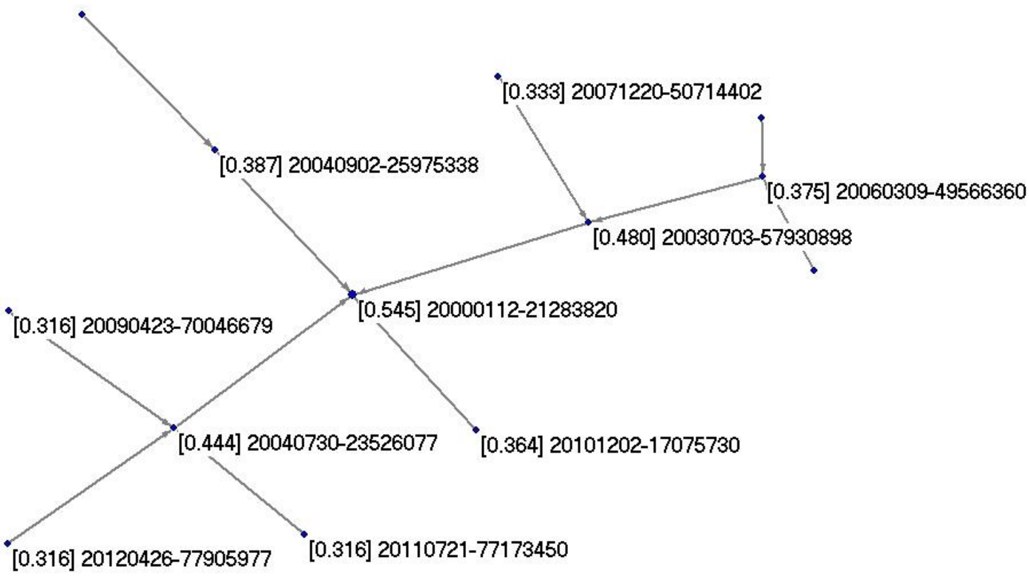

Figure 5.3.NP29. Closeness centrality of NP29

Authority weights (Figure 5.4.NP29, Table 5.10.NP29) – P29 is also the only authority patent in NP29.

Table 5.10.NP29. The authority patent of NP29

Rank	Vertex	Value	Id (Label)
1	1 (P29)	1	20000112-21283820

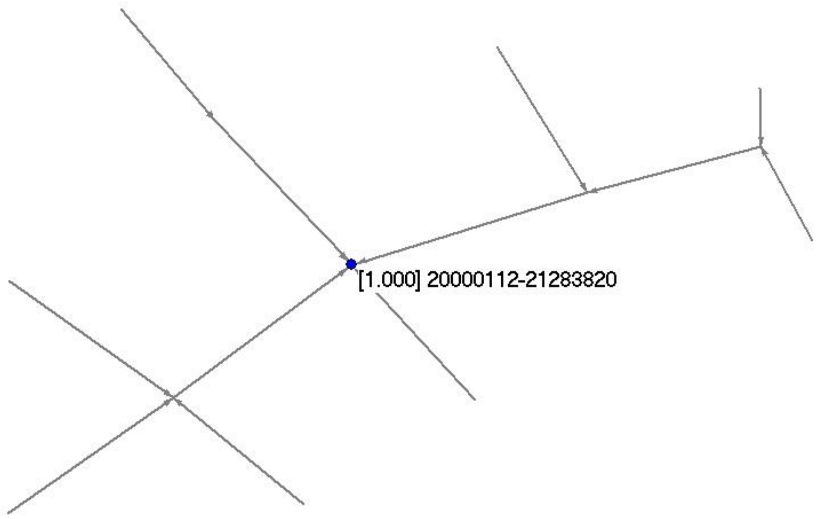

Figure 5.4.NP29. The authority patent of NP29

Hub patents (Figure 5.5.NP29, Table 5.11.NP29) – There four hubs in NP29, all with the same value of 0.50. The first (vertex 3) is the second most cited patent in NP29.

Table 5.11.NP29. The hub patents of NP29

Rank	Vertex	Value	Id (Label)
1	3	0.50	20040730-23526077
2	2	0.50	20030703-57930898
3	10	0.50	20101202-17075730
4	4	0.50	20040902-25975338

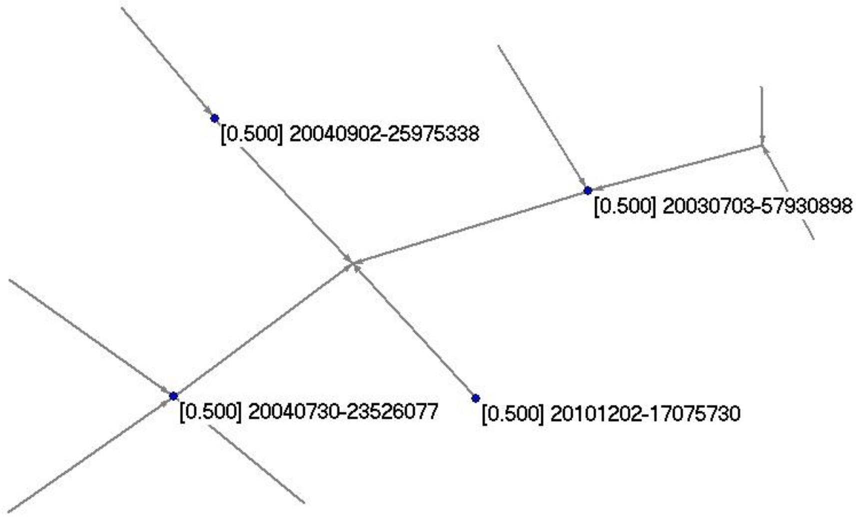

Figure 5.5.NP29. The hub patents of NP29

<u>*SPC (Figure 5.6.NP29, Table 5.12.NP29)*</u> – Figure 5.6.NP29 shows the technological trajectory of NP29 characterized by all 13 patents belonging to NP29. It departs from the P29, then has four important points around which other patents develop. The most important of these is vertex 3, the second is the European patent (vertex 4), owned by the French company Apollon Solar, with the title 'Method for production of a photovoltaic module and photovoltaic module produced by said method'. A third important point is the American patent (vertex 2) owned by the Emcore Corporation, with the title 'An apparatus and method for integral bypass diode in solar cells'. A fourth important point is a patent (vertex 5) owned by the University of Tokyo, with the title 'Stacked organic inorganic hybrid high efficiency solar cell'.

Table 5.12.NP29. Vertices on main path SPC [flow] of NP29

Rank	**Vertices**	**Cluster**	**Id (Label)**
1	1	1	20000112-21283820

2	2	1	20030703-57930898
3	3	1	20040730-23526077
4	4	1	20040902-25975338
5	5	1	20060309-49566360
6	6	1	20071220-50714402
7	7	1	20090423-70046679
8	8	1	20090701-69582896
9	9	1	20100407-68660604
10	10	1	20101202-17075730
11	11	1	20110721-77173450
12	12	1	20120426-77905977
13	13	1	20130110-79910788

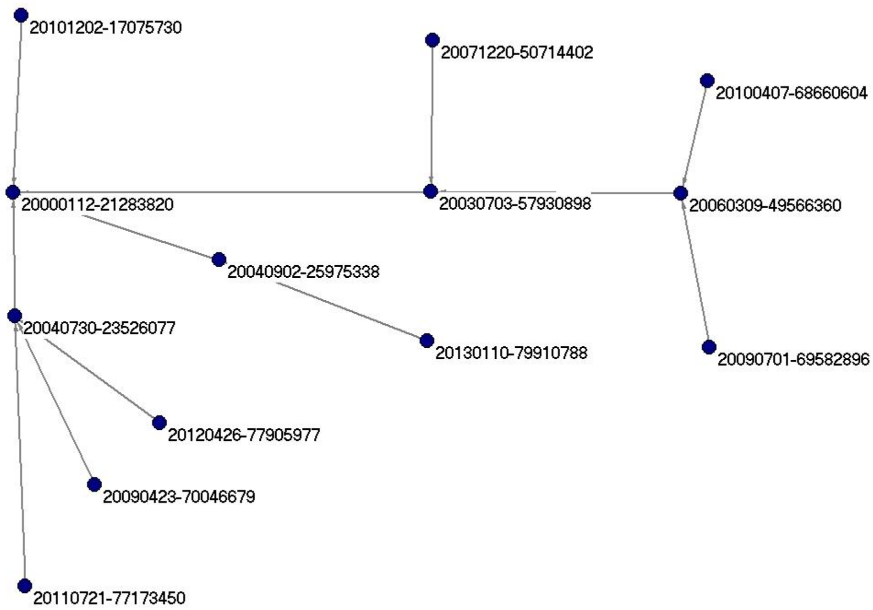

Figure 5.6.NP29. SPC of NP29

<u>Network and connectivity analysis of network built on P30 (NP30)- 20000209-21284021</u>

P30 is a European patent owned by the Japanese company Canon KK Corporation, with the title 'Solar cell module, solar cell module string, solar cell system, and method for supervising said solar cell module or solar cell module string' (IPC: G09F3/00). NP30 characteristics are given Table 5.7.NP30.

Table 5.7.NP30. Characteristics

Number of vertices (n)	**14**
	Arcs
Total number of lines	15
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.07
Average degree	2.14

<u>*In-degree centrality (Figure 5.1.NP30, Table 5.8.NP30)*</u> – P30 is the second most cited patent in NP30. The first most cited (vertex 3) is the European patent, owned by the German company Kopf, with the title 'Anti-theft device for a photovoltaic installation'.

Table 5.8.NP30. In-degree and out-degree centrality values of NP30

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	3	6	20071219-19093333	12	3	20110623-75940113
2	1 (P30)	5	20000209-21284021	7	1	20100128-71255577
3	2	3	20070118-21488328	13	1	20110929-76698260
4	4	1	20071221-21510929	6	1	20090402-70142052
5				11	1	20110615-72869849
6				10	1	20101007-71797921
7				9	1	20100817-71034232
8				8	1	20100405-73125514
9				14	1	20120629-76179058
10				3	1	20071219-19093333

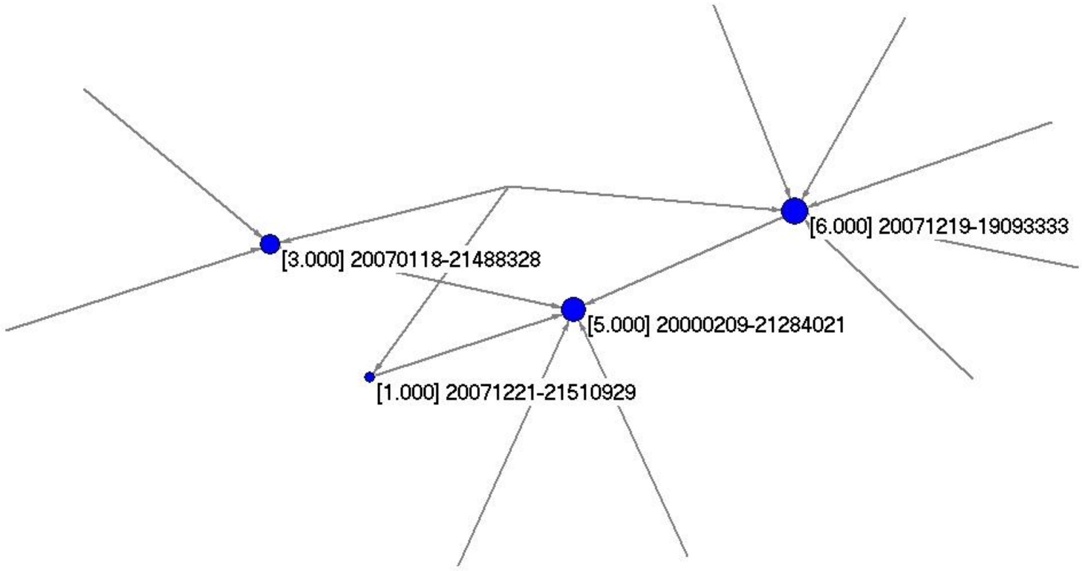

Figure 5.1.NP30. In-degree centrality of NP30

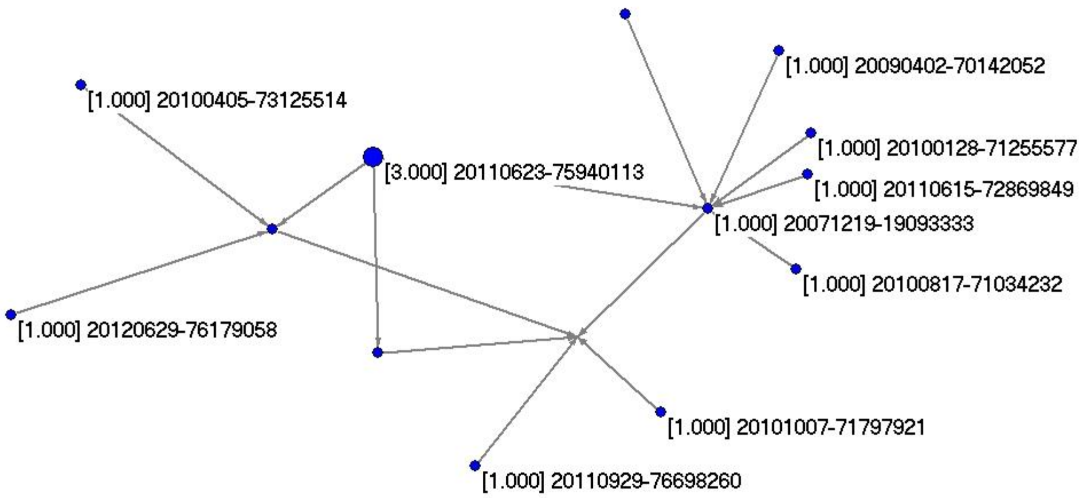

Figure 5.2.NP30. Out-degree centrality of NP30

Closeness centrality (Figure 5.3.NP30, Table 5.9.NP30) – According to the closeness centrality measure, P30 is ranked joint 1st among the top 10 patents together with vertex 3, with the values 0.62. This means that both patents are equally near to the centre of local clusters and are relatively close to all the others. The concept is more intuitively explained by

Figure 5.3.NP30, which shows the two patents lying at the centre of the surrounding clusters.

Table 5.9.NP30 closeness centrality values of NP30

Rank	Vertex	Value	Id (Label)
1	1 (P30)	0.62	20000209-21284021
2	3	0.62	20071219-19093333
3	12	0.52	20110623-75940113
4	2	0.48	20070118-21488328
5	4	0.42	20071221-21510929
6	10	0.39	20101007-71797921
7	9	0.39	20100817-71034232
8	7	0.39	20100128-71255577
9	13	0.39	20110929-76698260
10	11	0.39	20110615-72869849

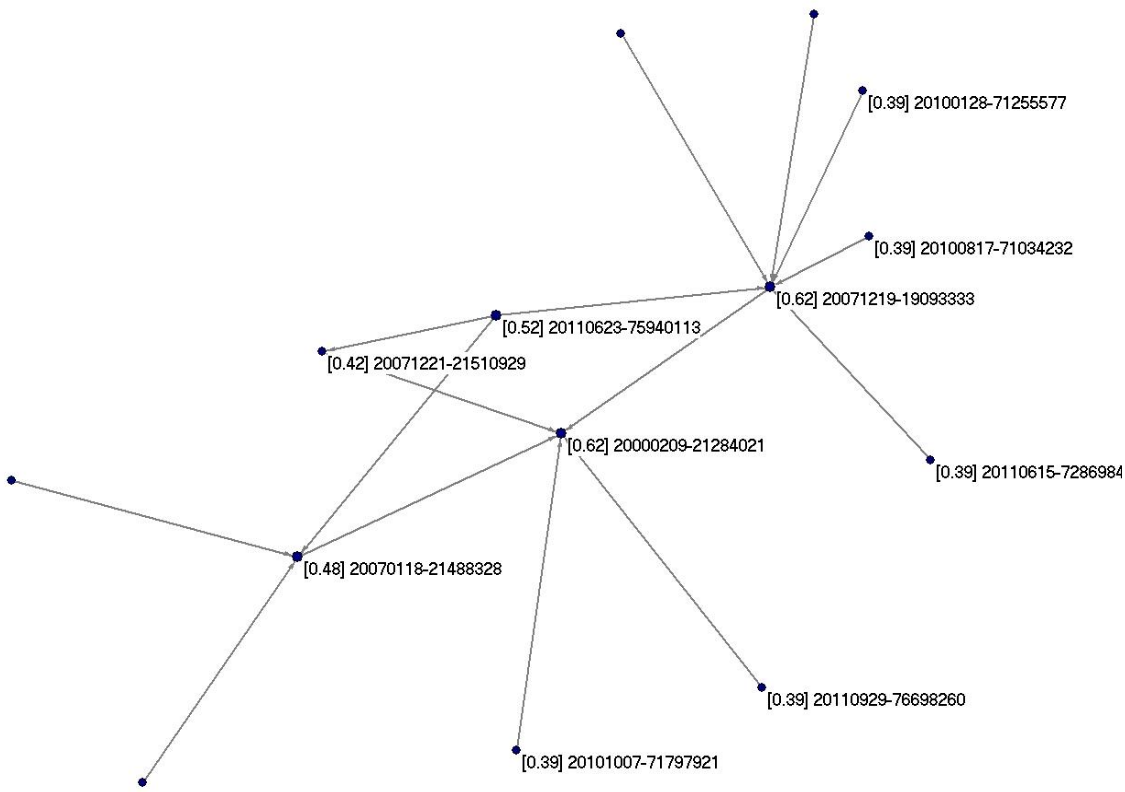

Figure 5.3.NP30. Closeness centrality of NP30

<u>*Authority weights (Figure 5.4.NP30, Table 5.10.NP30)*</u> – There are three authority patents along NP30. The first is vertex 3, already described as the most cited. The second

authority (vertex 2) is the American patent owned by the Renewable Energy Ventures, with the title 'Device for monitoring photovoltaic panels'. The third authority (vertex 4) is the patent owned by the German Kopf Corporation, with the title 'Theft protection unit for a photovoltaic unit'.

Table 5.10.NP30. The authority patents of NP30

Rank	Vertex	Value	Id (Label)
1	3	0.92	20071219-19093333
2	2	0.32	20070118-21488328
3	4	0.22	20071221-21510929

Figure 5.4.NP30. The authority patents of NP30

<u>*Hub weights (Figure 5.5.NP30, Table 5.11.NP30)*</u> – There are eight hub patents along NP30. The most important patent is vertex 12, owned by an Italian inventor, with the title 'Antitheft system for photovoltaic panels'.

Table 5.11.NP30. The hub patents of NP30

Rank	Vertex	Value	Id (Label)
1	12	0.57	20110623-75940113
2	7	0.35	20100128-71255577
3	6	0.35	20090402-70142052
4	5	0.35	20080814-00095686
5	11	0.35	20110615-72869849
6	9	0.35	20100817-71034232
7	14	0.12	20120629-76179058
8	8	0.12	20100405-73125514

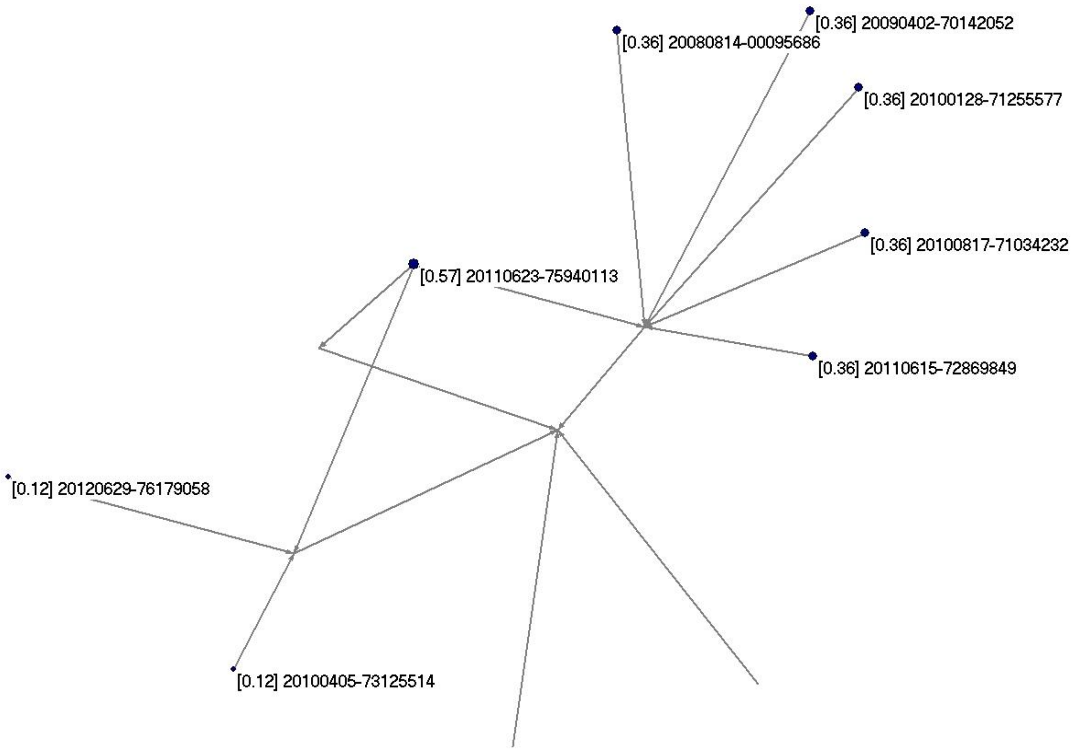

Figure 5.5.NP30. The hub patents of NP30

<u>*SPC (Figure 5.6.NP30, Table 5.12.NP30)*</u> – Figure 5.6.NP30 shows the technological trajectory of NP30 characterized by all 14 patents, with two focal points from which many other patents depart. These are the first two authority patents, vertex 3 and 2.

Table 5.12.NP30. Vertices on main path SPC [flow] of NP30

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000209-21284021
2	2	1	20070118-21488328

3	3	1	20071219-19093333
4	4	1	20071221-21510929
5	5	1	20080814-00095686
6	6	1	20090402-70142052
7	7	1	20100128-71255577
8	8	1	20100405-73125514
9	9	1	20100817-71034232
10	10	1	20101007-71797921
11	11	1	20110615-72869849
12	12	1	20110623-75940113
13	13	1	20110929-76698260
14	14	1	20120629-76179058

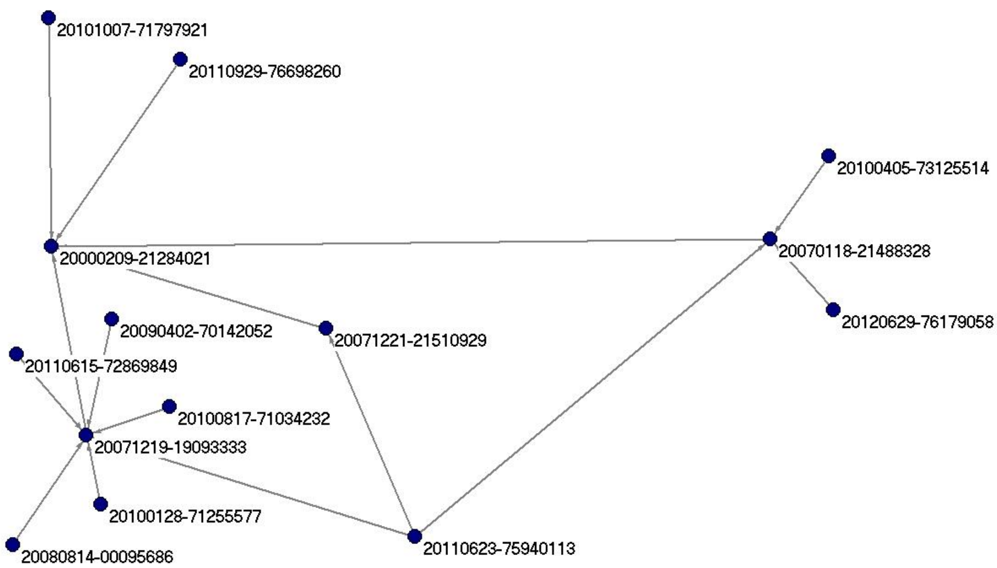

Figure 5.6.NP30. SPC of NP30

Network and connectivity analysis of network built on P32 (NP32)- 20000119-21288299

P32 is a European patent published by the Japanese Canon KK Corporation, with the title 'Processing method and apparatus for designing installation layout of solar cell modules in photovoltaic power generation system and computer program product storing the processing method' (IPC: E04D13/18). NP32 characteristics are given in Table 5.7.NP32.

Table 5.7.NP32. Characteristics

Number of vertices (n)	**13**
	Arcs
Total number of lines	12
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.07
Average degree	1.84

<u>*In-degree centrality (Figure 5.1.NP31, Table 5.8.NP32)*</u> – P32 is the most cited patent with nine citations. The other two patents obtained only two citations each. They are: vertex 9, the American patent owned by the Sunpower Corporation with the title 'Automated solar collector installation design including version management', and vertex 2 owned by three inventors from New Zealand, with the title 'Automated planning and design system, method and computer program'.

Table 5.8.NP32. In-degree and out-degree centrality values of NP32

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	1 (P32)	9	20000119-21288299	3	1	20041104-31990824
2	9	2	20100826-74323826	13	1	20130108-74323635
3	2	1	20040325-53799662	12	1	20121127-74179316
4				11	1	20120927-80816432
5				10	1	20120816-80456987
6				9	1	20100826-74323826
7				8	1	20100826-74323634
8				7	1	20100826-72731895
9				6	1	20100826-72730336
10				5	1	20100826-72726017

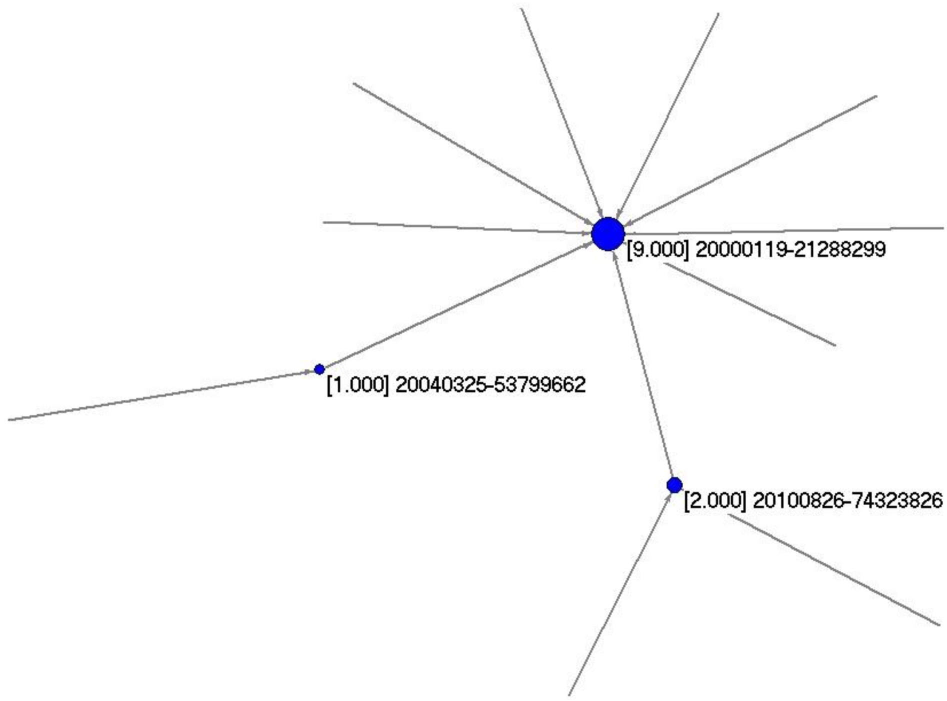

Figure 5.1.NP32. In-degree centrality of NP32

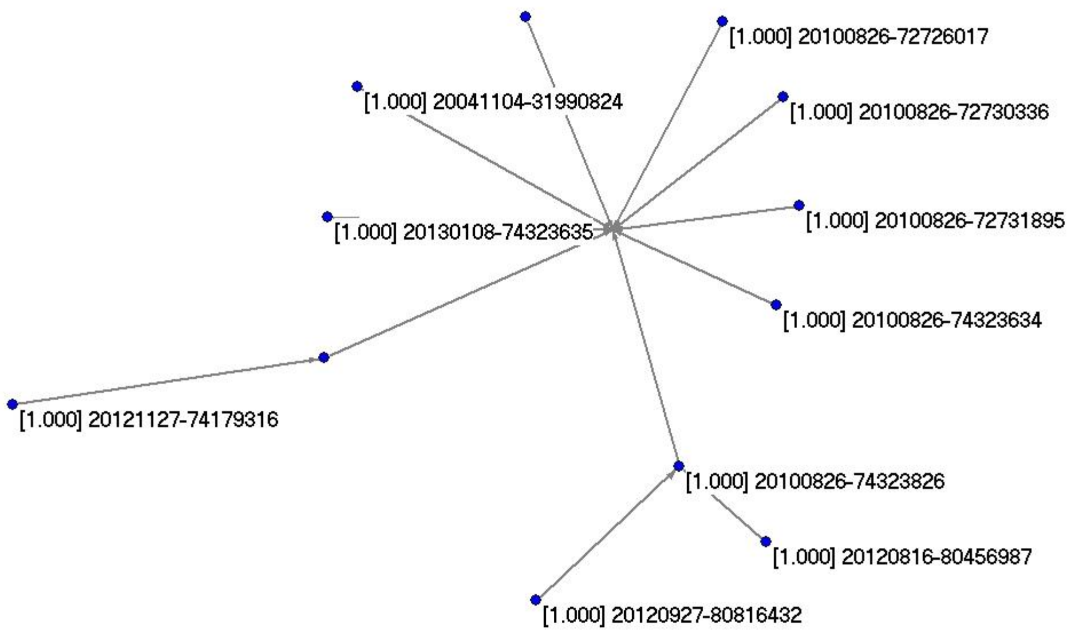

Figure 5.2.NP32. Out-degree centrality of NP32

Closeness centrality (Figure 5.3.NP32, Table 5.9.NP32) – P32 is ranked 1st in the top 10 patents according to the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP32, which shows P32 lying at the centre of the surrounding clusters.

Table 5.9.NP32. Closeness centrality values of NP32

Rank	Vertex	Value	Id (Label)
1	1 (P32)	0.80	20000119-21288299
2	9	0.54	20100826-74323826
3	2	0.50	20040325-53799662
4	3	0.46	20041104-31990824
5	7	0.46	20100826-72731895
6	4	0.46	20100826-72726013
7	8	0.46	20100826-74323634
8	6	0.46	20100826-72730336
9	5	0.46	20100826-72726017
10	13	0.46	20130108-74323635

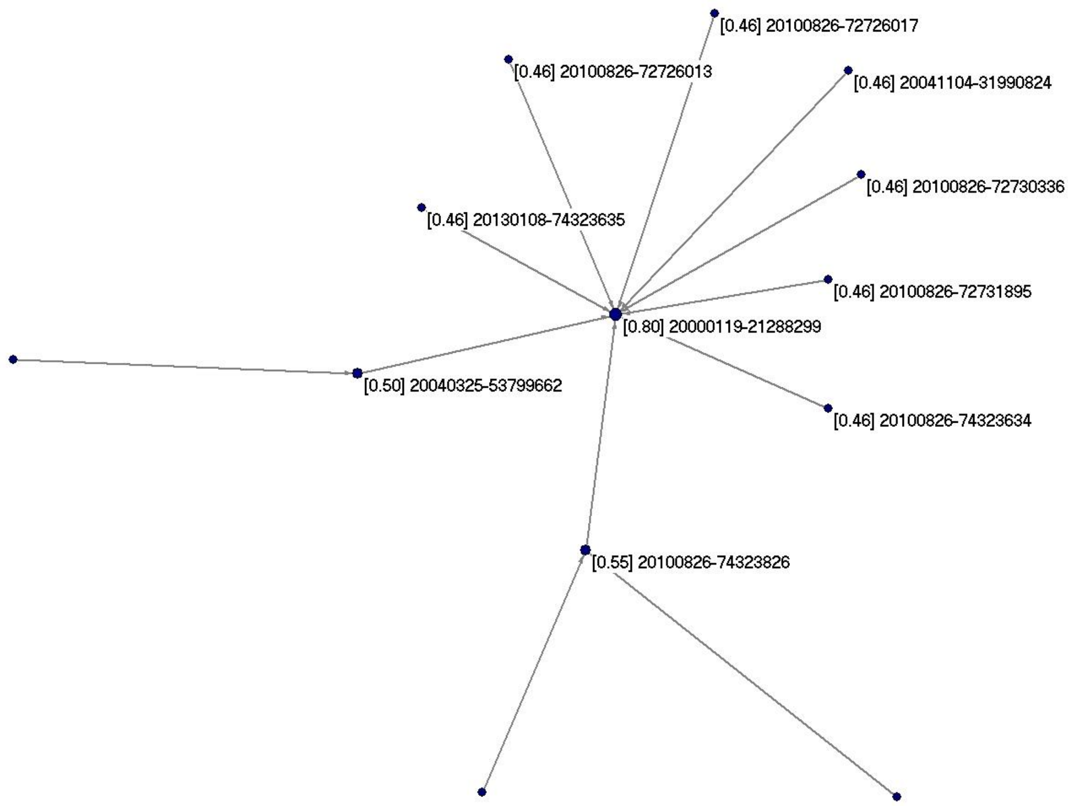

Figure 5.3.NP32. Closeness centrality of NP32

<u>*Authority weights (Figure 5.4.NP32, Table 5.10.NP32)*</u> – P32 is the only authority in NP32.

Table 5.10.NP32. The authority patent of NP32

Rank	Vertex	Value	Id (Label)
1	1 (P32)	1	20000119-21288299

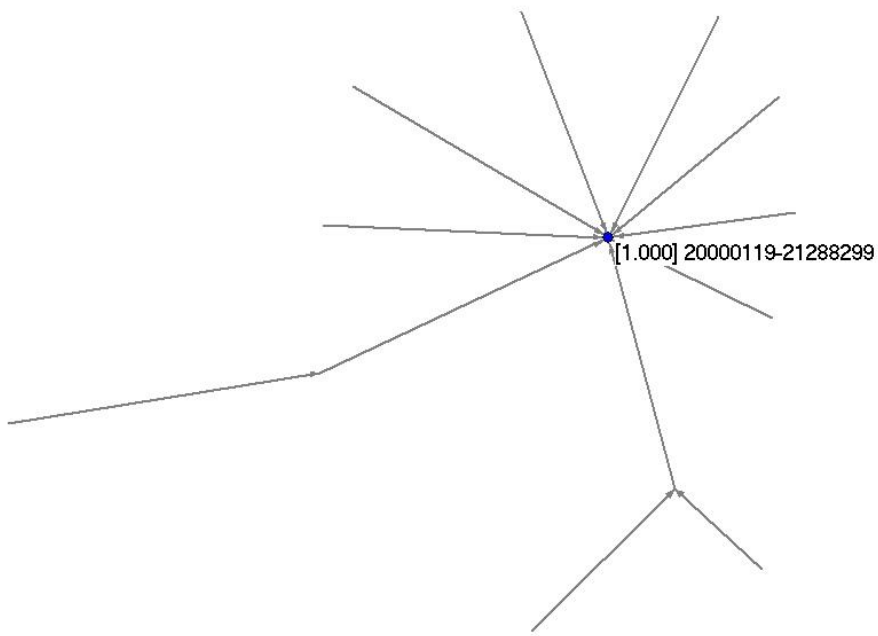

Figure 5.4.NP32. The authority patent of NP32

<u>*Hub weights (Figure 5.5.NP32, Table 5.11.NP32)*</u> – There are nine hub patents in NP32, which are equally important. The first is vertex 3 owned by the Japanese company Sharp, with the title 'Solar cell ordering system'.

Table 5.11.NP32. The hub patents of NP32

Rank	Vertex	Value	Id (Label)
1	3	0.33	20041104-31990824
2	13	0.33	20130108-74323635
3	7	0.33	20100826-72731895
4	6	0.33	20100826-72730336
5	2	0.33	20040325-53799662

6	9	0.33	20100826-74323826
7	8	0.33	20100826-74323634
8	5	0.33	20100826-72726017
9	4	0.33	20100826-72726013

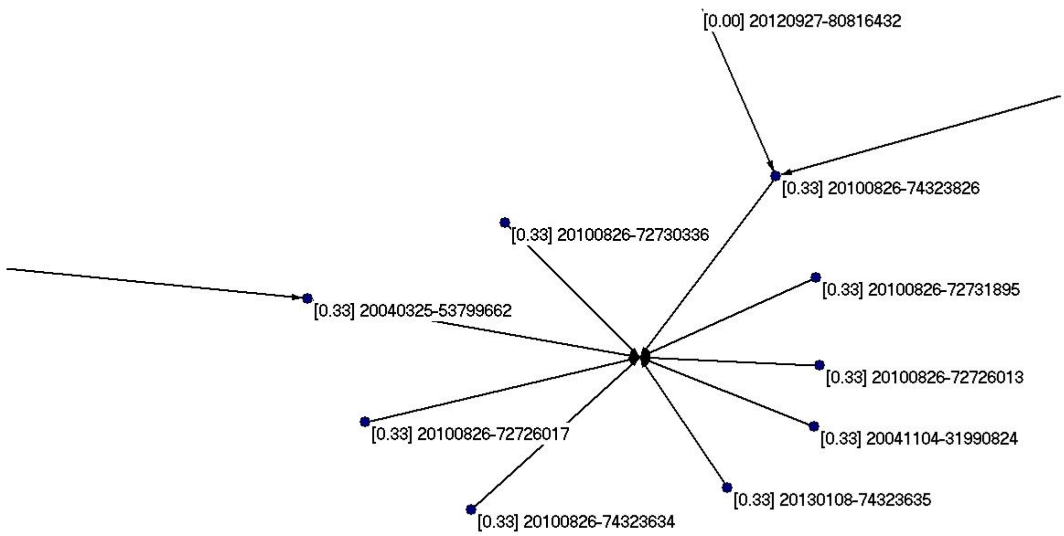

Figure 5.5.NP32. The hub patents of NP32

<u>SPC (Figure 5.6.NP32, Table 5.12.NP32)</u> – Figure 5.6.NP32 shows the technological trajectory of NP32. It departs from P32 and has a second important point (vertex 9) in the American patent, owned by the Solar Corporation with the title 'Automated solar collector installation design including version management'. From this point depart two other patents published in 2012.

Table 5.12.NP32. Vertices on main path SPC [flow] of NP32

Rank	**Vertex**	**Cluster**	**Id (Label)**
1	1	1	20000119-21288299
2	13	1	20130108-74323635
3	12	1	20121127-74179316
4	11	1	20120927-80816432
5	10	1	20120816-80456987
6	9	1	20100826-74323826
7	8	1	20100826-74323634
8	7	1	20100826-72731895
9	6	1	20100826-72730336
10	5	1	20100826-72726017

11	4	1	20100826-72726013
12	3	1	20041104-31990824
13	2	1	20040325-53799662

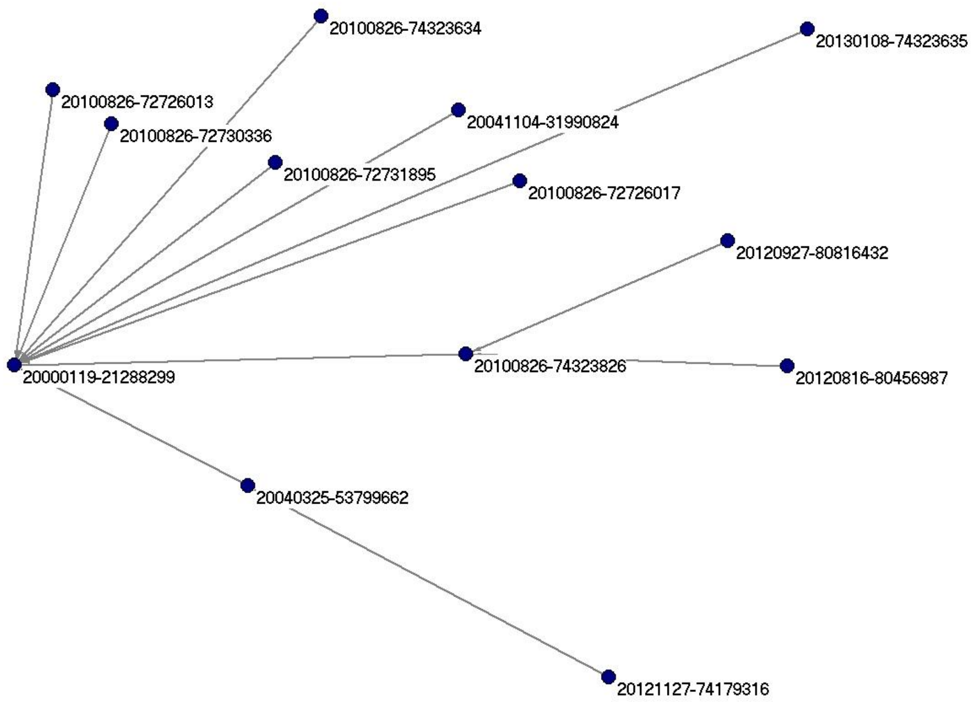

Figure 5.6.NP32. SPC of NP32

Network and connectivity analysis of network built on P33 (NP33)- **20000202-21289303**

P33 is a European patent, published by a Swiss private inventor, with the title 'Building element for roof and/or façade covering and its manufacturing method' (IPC: E04B7/22). NP33 is a very small network, its characteristics are given in Table 5.7.NP33.

Table 5.7.NP33. Characteristics

Number of vertices (n)	**5**
	Arcs
Total number of lines	6
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.24
Average degree	2.40

In-degree centrality (Figure 5.1.NP33, Table 5.8.NP33) – P33 and vertex 2 are the most cited, with two citations each. The latter is a patent published simultaneously in different countries, by a German Inventor, with the title 'Building wall with fluidic leadthroughs energy barriers'.

Table 5.8.NP33. In-degree centrality values of NP33

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	1 (P33)	2	20000202-21289303	3	2	20111004-68811412
2	2	2	20070125-21480369	5	1	20100729-73898688
3	3	1	20111004-68811412	4	1	20120508-78388018
4				2	1	20070125-21480369

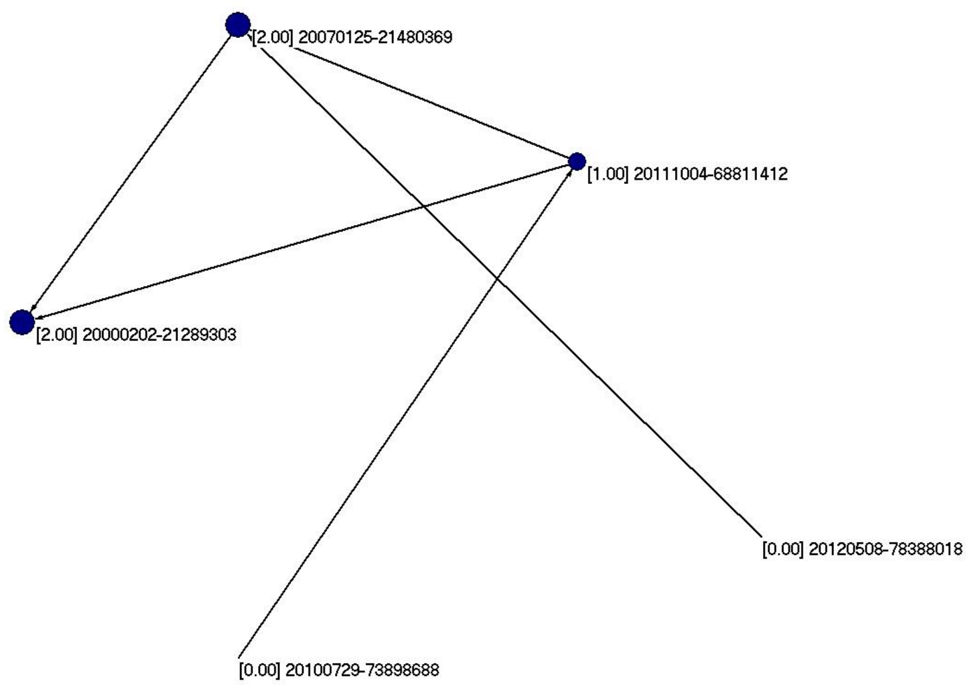

Figure 5.1.NP33. In-degree centrality of NP33

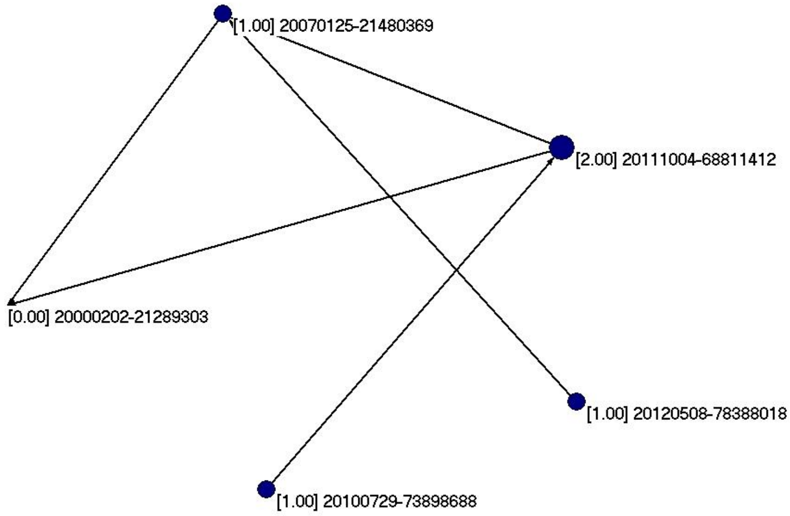

Figure 5.2.NP33. Out-degree centrality of NP33

Closeness centrality (Figure 5.2.NP33, Table 5.9.NP33) – For closeness to other patents, two patents have the same value (0.80). The first one (vertex 3) is an American patent published by Kinspan Research and Developments Ltd, with the title 'Panel'. Vertex 2 has been described already as one of the most cited.

Table 5.9.NP33. Closeness centrality values of NP33

Rank	Vertex	Value	Id (Label)
1	3	0.80	20111004-68811412
2	2	0.80	20070125-21480369
3	1 (P33)	0.67	20000202-21289303
4	4	0.50	20120508-78388018
5	5	0.50	20100729-73898688

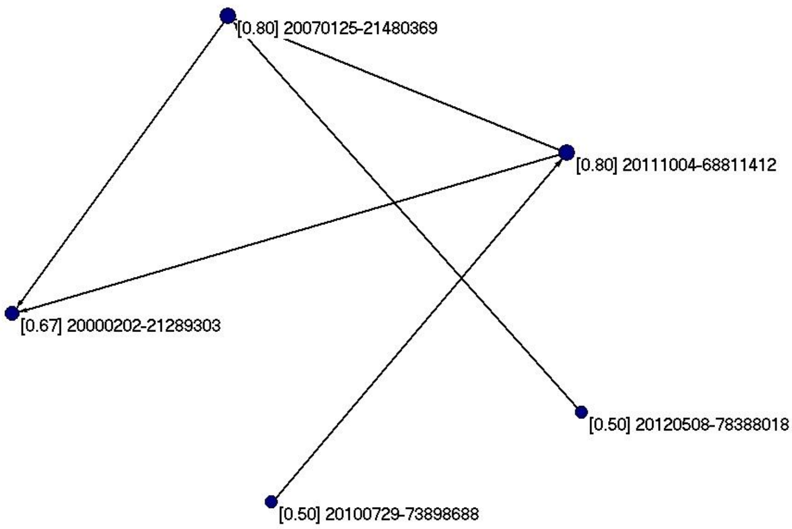

Figure 5.3.NP32. Closeness centrality of NP32

Authority weights (Figure 5.4.NP33, Table 5.10.NP33) – P33 is one authority in NP33. The other is the second most cited patent (vertex 2), already described.

Table 5.10.NP33. The authority patents of NP33

Rank	Vertex	Value	Id (Label)
1	1 (P33)	0.71	20000202-21289303
2	2	0.71	20070125-21480369

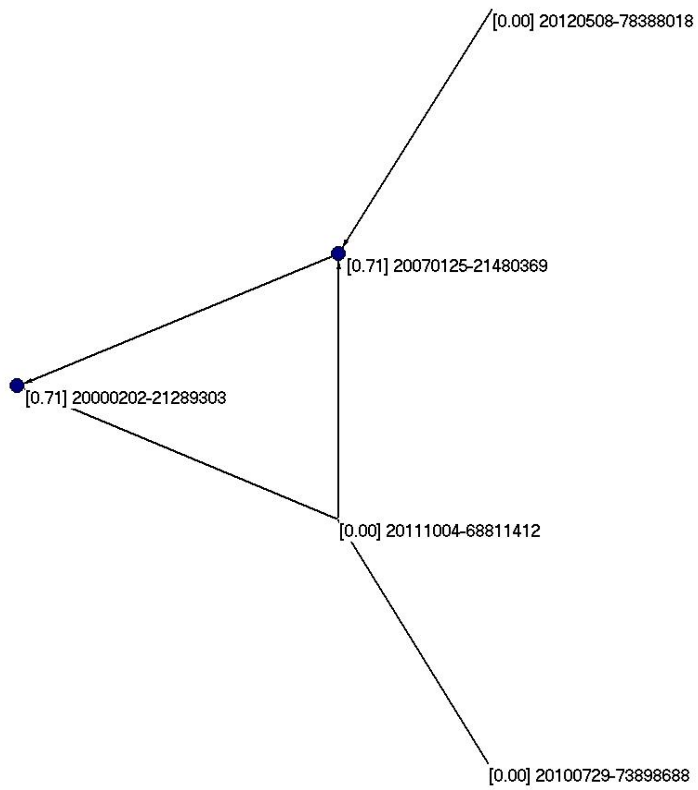

Figure 5.4.NP33. The authority patents of NP33

<u>*Hub weights (Figure 5.5.NP33, Table 5.11.NP33)*</u> – The most important hub (vertex 3) was described in the 'closeness centrality' section. The other two hubs are two American patents, vertex 2 already described, and vertex 4 published by a private inventor and the Kinspan Research and Developments Ltd, with the title 'Panel'.

Table 5.11.NP33. The hub patents of NP33

Rank	Vertex	Value	Id (Label)
1	3	0.82	20111004-68811412
2	2	0.41	20070125-21480369
3	4	0.40	20120508-78388018

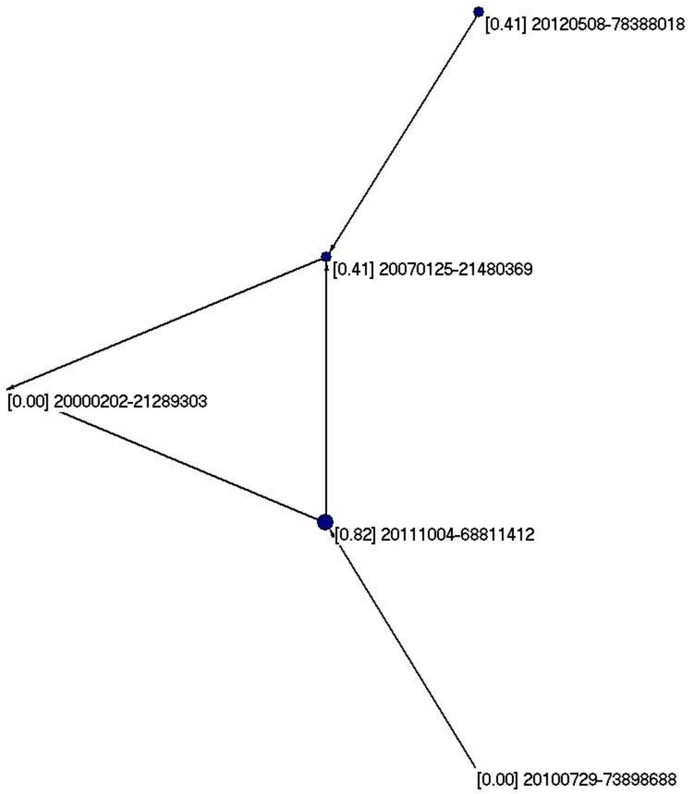

Figure 5.5.NP33. The hub patents of NP33

<u>*SPC (Figure 5.6.NP33, Table 5.12.NP33)*</u> – The technological trajectory of NP33 is depicted in Figure 5.6.NP33. The five patents, already described, all belong to the NP33 trajectory.

Table 5.12.NP33. Vertices on main path SPC [flow] of NP33

Rank	Vertex	Cluster	Id (Label)
1	1 (P33)	1	20000202-21289303
2	5	1	20100729-73898688
3	3	1	20111004-68811412
4	2	1	20070125-21480369
5	4	1	20120508-78388018

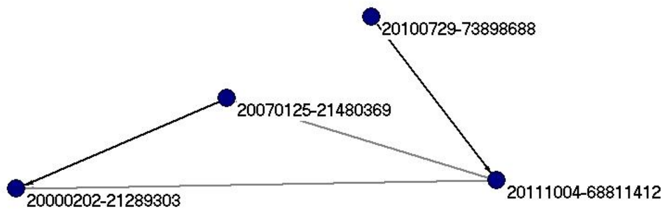

Figure 5.6.NP33. SPC of NP33

Network and connectivity analysis of network built on P34 (NP34) - 20000308-21290893

P34 is a European patent published by the American TRW Corporation, with the title 'Combined photovoltaic array and RF reflector' (IPC: B64G1/22). NP34 characteristic are given in Table 5.7.NP34.

Table 5.7.NP34. Characteristics

Number of vertices (n)	**3**
	Arcs
Total number of lines	2
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.22
Average degree	1.33

In-degree centrality (Figure 5.1.NP34, Table 5.8.NP34) – P34 is the most cited patent of the small NP34.

Table 5.8.NP34. In-degree centrality values of NP34

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	1(P34)	2	20000308-21290893	2	1	20050317-17054195
2				3	1	20110810-75825682

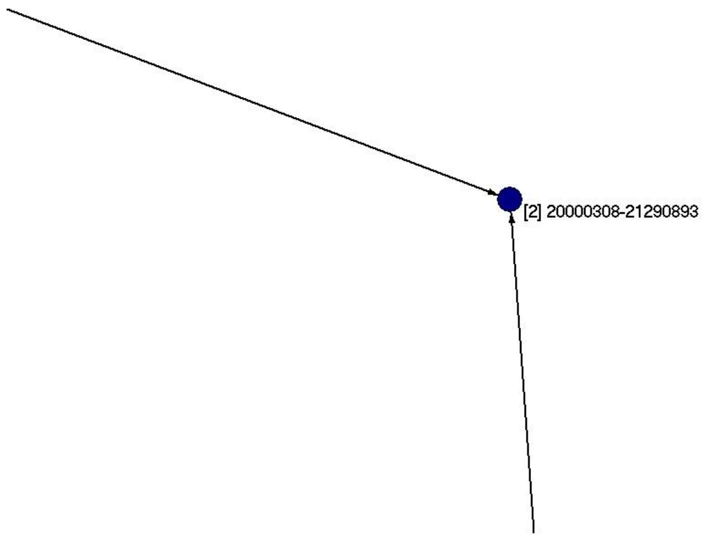

Figure 5.1.NP34. In-degree centrality of NP34

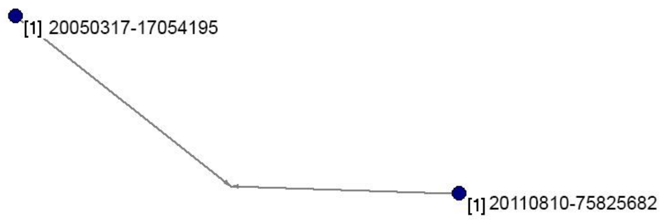

Figure 5.2.NP34. Out-degree centrality of NP34

Closeness centrality (Figure 5.3.NP34, Table 5.9.NP34) – P34 is also the most close to the centre and to the others according to the closeness centrality measure.

Table 5.9.NP34. Closeness centrality values of NP34

Rank	Vertex	Value	Id (Label)
1	1 (P34)	1	20000308-21290893
2	2	0.67	20050317-17054195
1	3	0.67	20110810-75825682

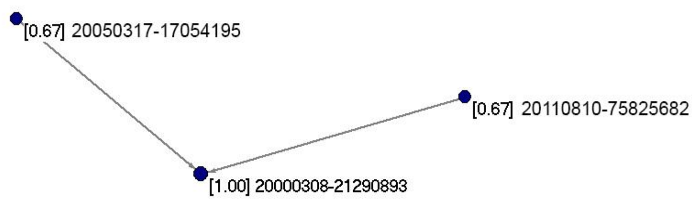

Figure 5.3.NP34. Closeness centrality of NP34

<u>*Authority weights (Figure 5.4.NP34, Table 5.10.NP34)*</u> – P34 is the only authority in NP34.

Table 5.10.NP34. The authority patent of NP34

Rank	Vertex	Value	Id (Label)
1	1 (P34)	1	20000308-21290893

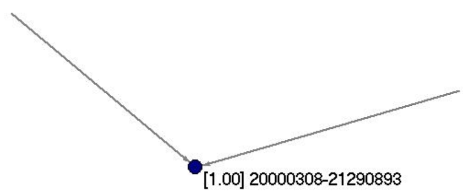

Figure 5.4.NP34. The authority patent of NP34

<u>*Hub weights (Figure 5.5.NP34, Table 5.11.NP34)*</u> – The best developments of P34 are:

- vertex 2, published in several countries by a German private inventor, entitled 'Parabolic antenna provided with an attachment or several attachment elements on the outer edge',

- vertex 3, published in Europe by the American Harris Corporation, with the title 'Extendable rib reflector'.

Table 5.11.NP34. The hub patents of NP34

Rank	Vertex	Value	Id (Label)
1	2	0.77	20050317-17054195
2	3	0.77	20110810-75825682

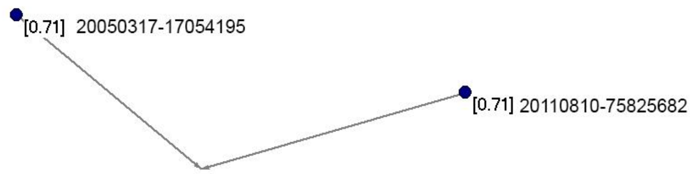

Figure 5.5.NP34. The hub patents of NP34

<u>*SPC (Figure 5.6.NP34, Table 5.12.NP34)*</u> – The technological trajectory of NP34 is depicted by Figure 5.6.NP34.

Table 5.12.NP34. Vertices on main path SPC [flow] of NP34

Rank	Cluster	Id (Label)
1	1	20000308-21290893
2	1	20050317-17054195
3	1	20110810-75825682

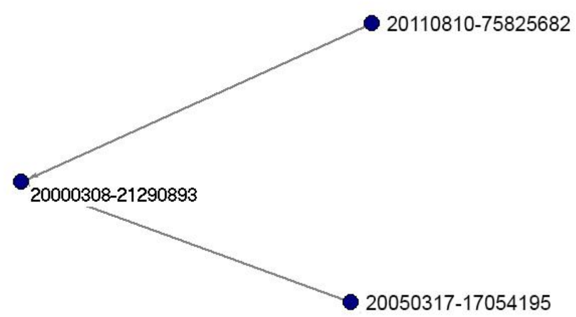

Figure 5.6.NP34. SPC of NP34

Network and connectivity analysis of network built on P35 (NP35)- 20000412-21292101

P35 is a European patent entitled 'Solar generator with solar cells fixed in series on a supporting frame' (IPC: H01L31/042) and published by a German private inventor. NP35 characteristics are given in Table 5.7.NP35.

Table 5.7.NP35. Characteristics

Number of vertices (n)	**17**
	Arcs
Total number of lines	18
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.06
Average degree	2.11

In-degree centrality (Figure 5.1.NP35, Table 5.8.NP35) – P35 is the most cited patent in NP35, with six citations.

Table 5.8.NP35. In-degree and out-degree centrality values of NP35

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	1 (P35)	6	20000412-21292101	13	2	20120524-79706208
2	2	5	20090617-68673765	8	2	20120209-79073234
3	14	4	20120814-74528090	16	1	20121127-74528088
4	15	1	20120904-74526975	7	1	20120209-79073218
5	12	1	20120517-79670990	15	1	20120904-74526975
6	16	1	20121127-74528088	6	1	20110906-77478422
7				12	1	20120517-79670990
8				11	1	20120426-79561668
9				10	1	20120223-79163984
10				9	1	20120212-75321378

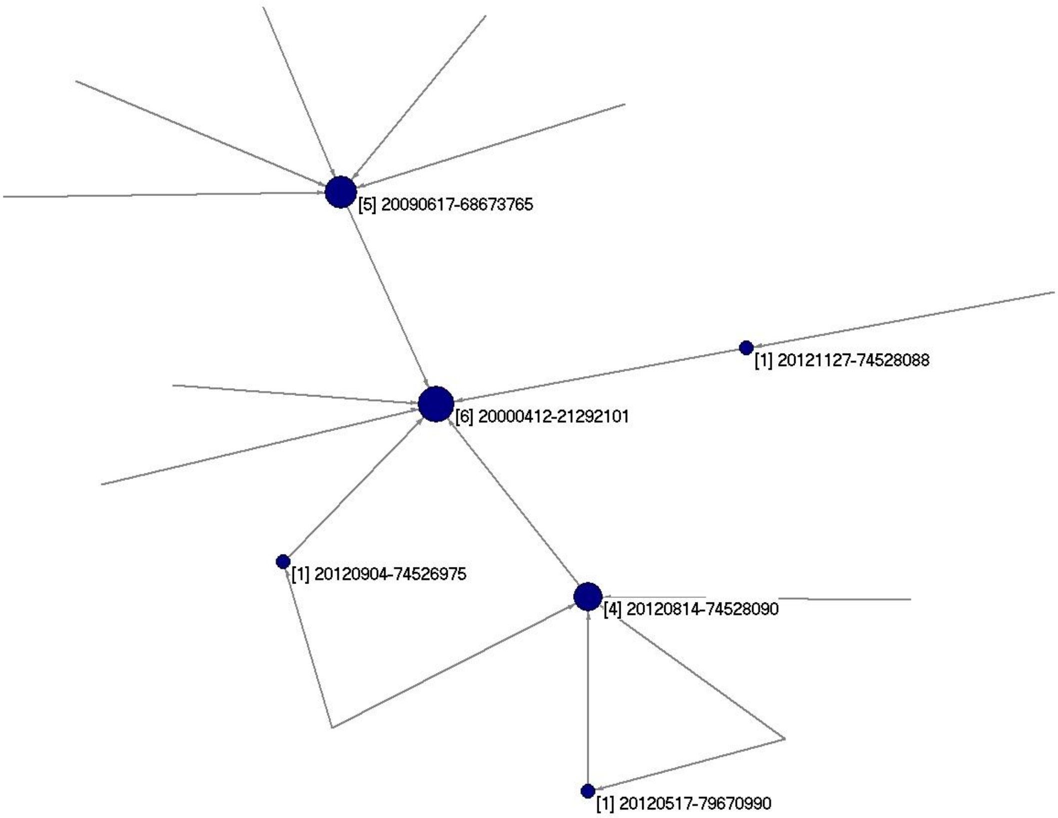

Figure 5.1.NP35. In-degree centrality of NP35

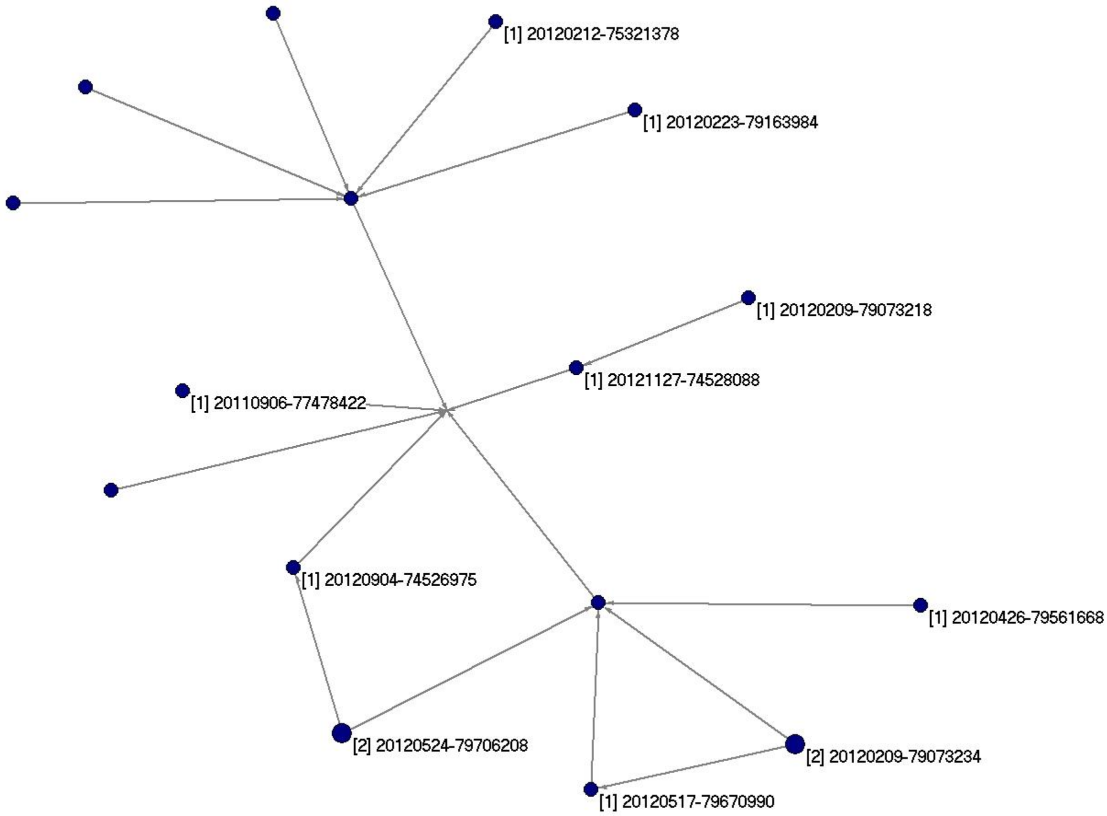

Figure 5.2.NP35. Out-degree centrality of NP35

<u>*Closeness centrality (Figure 5.3.NP35, Table 5.9.NP35)*</u> – P35 is ranked 1st among the top 10 patents according to the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP35, which shows P35 lying at the centre of the surrounding clusters.

Table 5.9.NP35. Closeness centrality values of NP35

Rank	**Vertex**	**Value**	**Id (Label)**
1	1 (35)	0.62	20070821-62398637
2	2	0.52	20080515-29436452
3	14	0.48	20071221-00078925
4	15	0.41	20001220-00495792
5	16	0.39	20051215-07096762
6	3	0.39	20110621-71003687
7	6	0.35	20090813-70444497
8	13	0.35	20091231-72194927
9	5	0.35	20090129-69275079

10	9	0.35	20080611-19246728

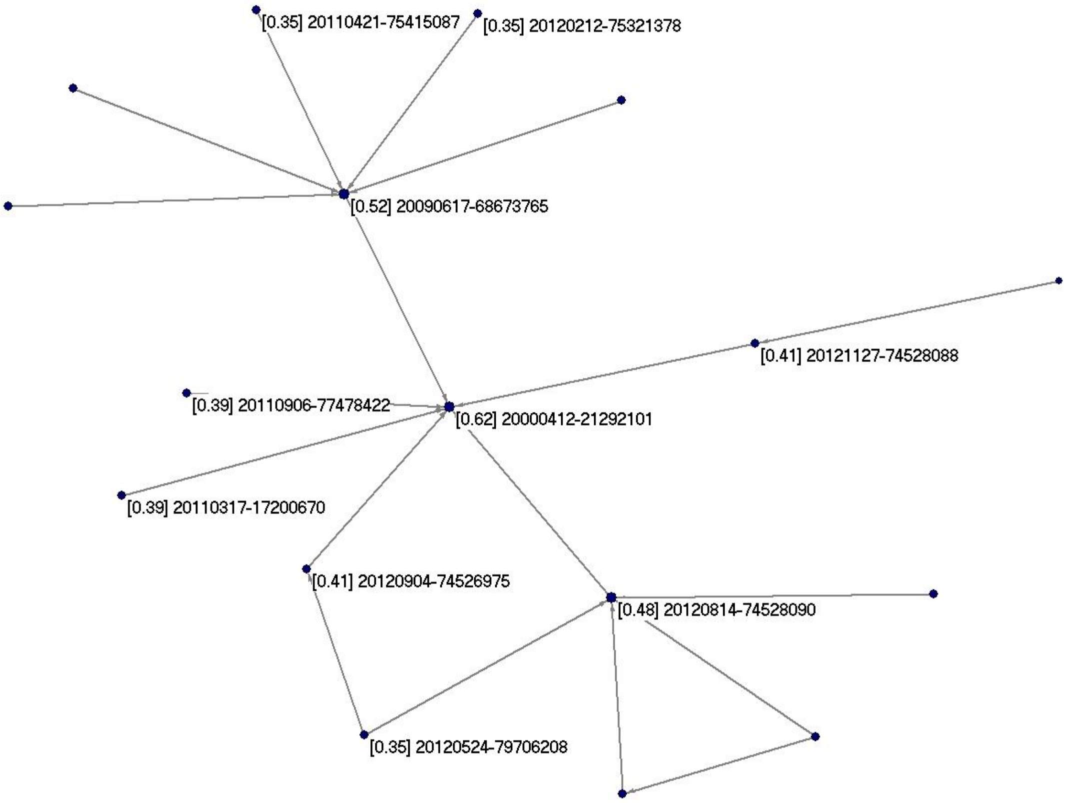

Figure 5.3.NP35 closeness centrality of NP35

Authority weights (Figure 5.4.NP35, Table 5.10.NP35) – There are two authority patents in NP35 which have been described already as the most cited patents, P35 and vertex 2.

Table 5.10.NP35. The authority patents of NP35

Rank	Vertex	Value	Id (Label)
1	1 (P35)	1	20000412-21292101
2	2	0.05	20090617-68673765

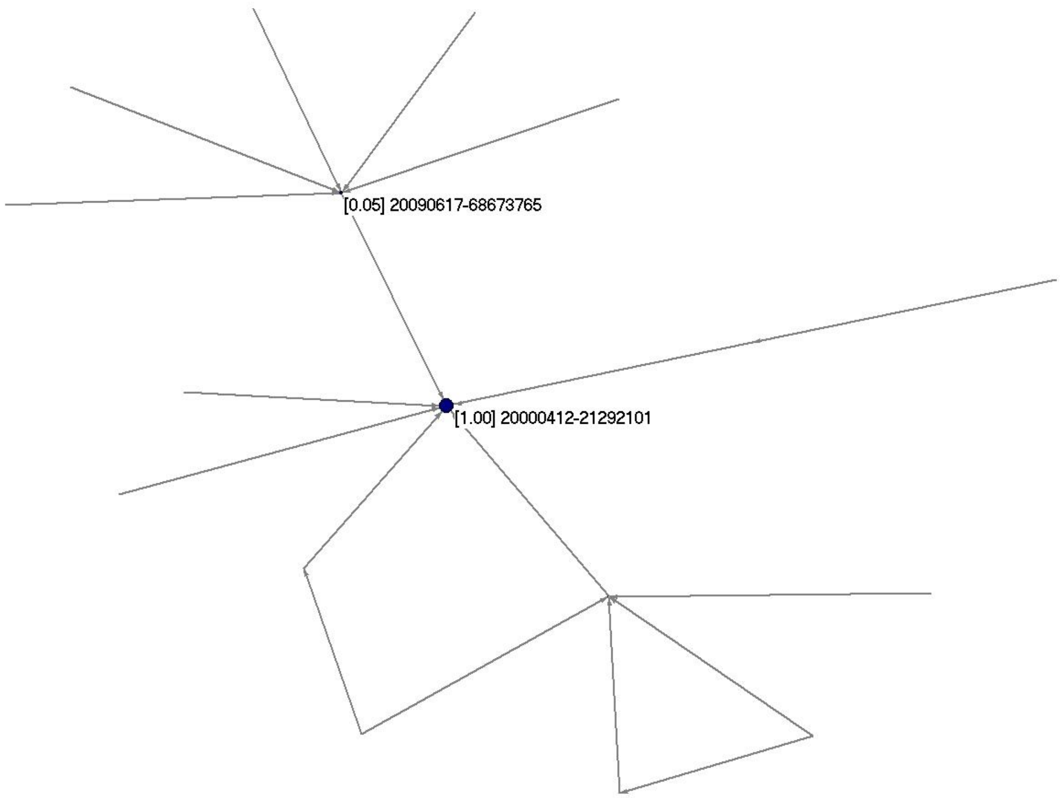

Figure 5.4.NP35. The authority patents of NP35

Hub weights (Figure 5.5.NP35, Table 5.11.NP35) – There are six equally important best developments of the core inventions:

- vertex 3, published in Europe by a private inventor, with the title 'Combined photoelectric formwork for curtain wall glass';
- vertex 15, published in the US, by the Northern States Metal company, with the title 'Support system for solar panel';
- vertex 14, published in the US, and a different version of the previous patent published by the same company with the same title;
- vertex 6, published in the US by a private inventor with the title 'Integrated photovoltaic modular panel for a curtain wall glass';
- vertex 2, already described as the second most cited patent.

Table 5.11.NP35. The hub patents of NP35

Rank	Vertex	Value	Id (Label)
1	3	0.41	20110317-17200670
2	15	0.41	20120904-74526975
3	14	0.41	20120814-74528090
4	6	0.41	20110906-77478422
5	2	0.41	20090617-68673765
6	16	0.41	20121127-74528088

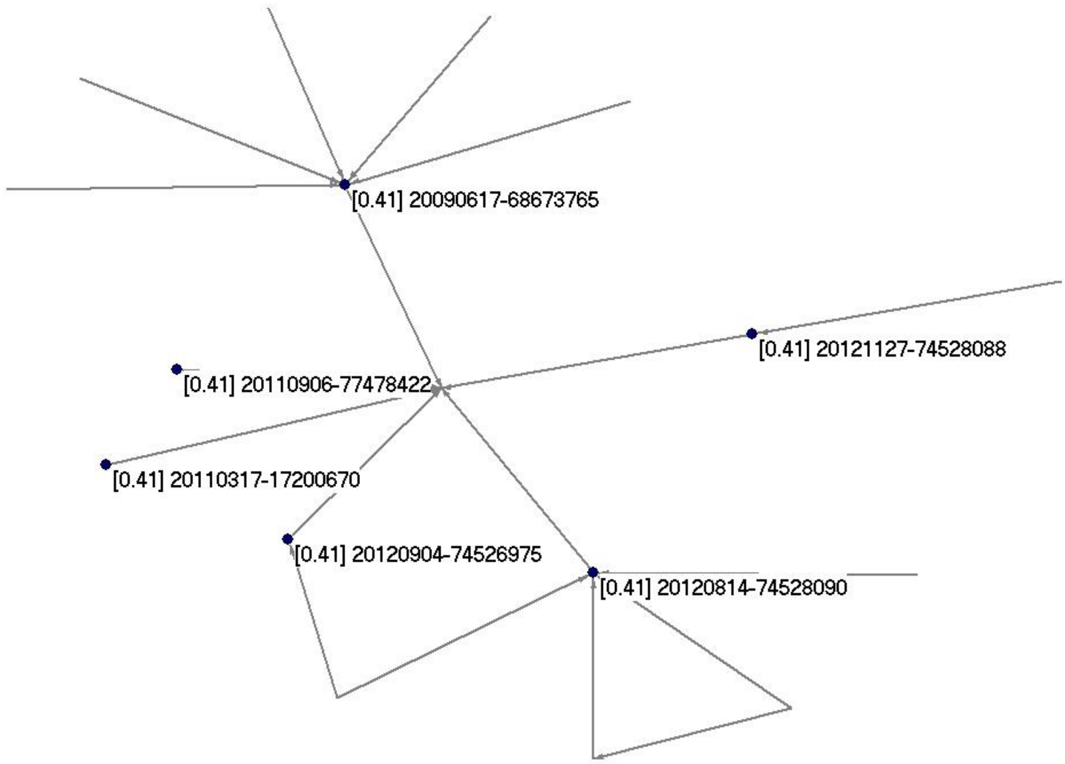

Figure 5.5.NP35. The hub patents of NP35

<u>*SPC (Figure 5.6.NP35, Table 5.12.NP35)*</u> – The technological trajectory of NP35, depicted in Figure 5.6.NP35, goes from P35 to an Italian patent (vertex 17) published by Sapa Profili SRL, with the original title of 'Pensilina fotovoltaica'.

Table 5.12.NP35. Vertices on main path SPC [flow] of NP35

Rank	Vertices	Cluster	Id (Label)
1	1	1	20000412-21292101
2	2	1	20090617-68673765
3	3	1	20110317-17200670
4	4	1	20110415-72043701
5	5	1	20110421-75415087

6	6	1	20110906-77478422
7	7	1	20120209-79073218
8	8	1	20120209-79073234
9	9	1	20120212-75321378
10	10	1	20120223-79163984
11	11	1	20120426-79561668
12	12	1	20120517-79670990
13	13	1	20120524-79706208
14	14	1	20120814-74528090
15	15	1	20120904-74526975
16	16	1	20121127-74528088
17	17	1	20121225-77254134

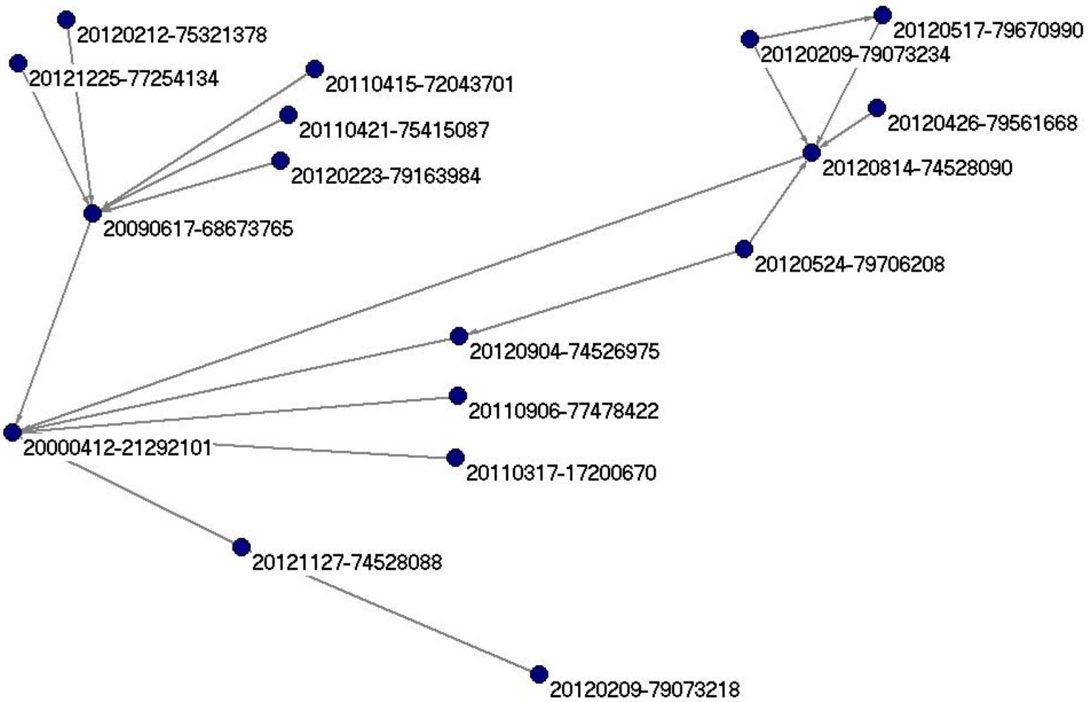

Figure 5.6.NP35 SPC of NP35

<u>Network and connectivity analysis of network built on P36 (NP36)- 20000927-21298078</u>

P36 is a European patent published by the Japanese Kaneka Corporation, with the title 'Structure and method for installing photovoltaic module' (IPC: E04D12/00). NP36 characteristics are given in Table 5.7.NP36.

Table 5.7.NP36. Characteristics

Number of vertices (n)	**76**
	Arcs
Total number of lines	99
Number of loops	0
Number of multiple lines	14
Density [loops allowed]	0.07
Average degree	2.60

<u>*In-degree centrality (Figure 5.1.NP36, Table 5.8.NP36)*</u> – According to the in-degree centrality measure, P36 is the 8th most cited patent, with three citations. The 1st most cited patent is vertex 3, published simultaneously in several countries, with the title 'Support frame for panel-type solar cell modules or solar collector modules'.

Table 5.8.NP36. Top 10 in-degree and out-degree centrality values of NP36

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	3	21	20060824-01695682	60	3	20121010-81179550
2	4	14	20080723-00019205	30	2	20110831-73785036
3	9	9	20100512-73283052	29	2	20110825-75940053
4	15	7	20101202-74994053	59	2	20120927-80752430
5	5	5	20080828-17328285	58	2	20120926-79362677
6	2	5	20030226-00225193	44	2	20120207-76698044
7	8	4	20100505-71801202	9	2	20100512-73283052
8	1 (P36)	3	20000927-21298078	70	2	20121205-79830823
9	6	3	20090122-69255737	66	2	20121121-79538640
10	21	3	20110505-76334141	68	2	20121122-81573160

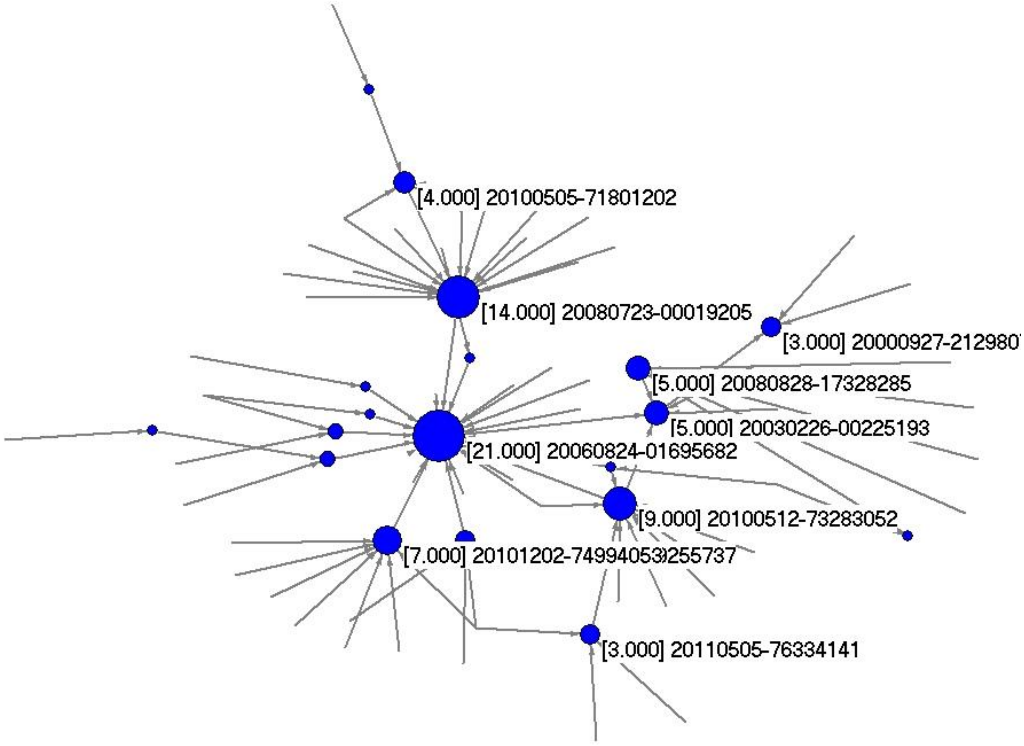

Figure 5.1.NP36. In-degree centrality of NP36

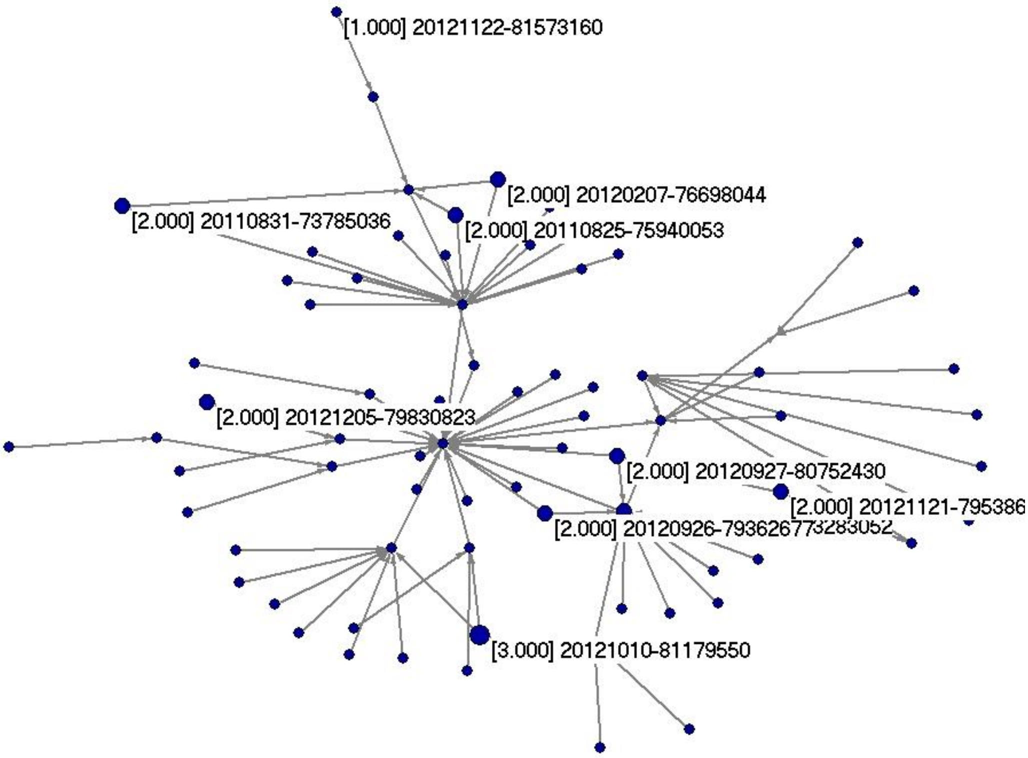

Figure 5.2.NP36. Out-degree centrality of NP36

Closeness centrality (Figure 5.3.NP36, Table 5.9.NP36) - According to the closeness centrality measure, 1st ranked among the top 10 patents is vertex 3, which is also the most cited patent. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP36, which shows the patent lying at the centre of the surrounding clusters.

Table 5.9.NP36. Closeness centrality values of NP36

Rank	Vertex	Value	Id (Label)
1	3	0.53	20060824-01695682
2	9	0.41	20100512-73283052
3	2	0.41	20030226-00225193
4	4	0.41	20080723-00019205
5	15	0.38	20101202-74994053
6	59	0.37	20120927-80752430
7	58	0.37	20120926-79362677
8	6	0.36	20090122-69255737
9	43	0.36	20120131-69217866
10	18	0.36	20110421-74830366

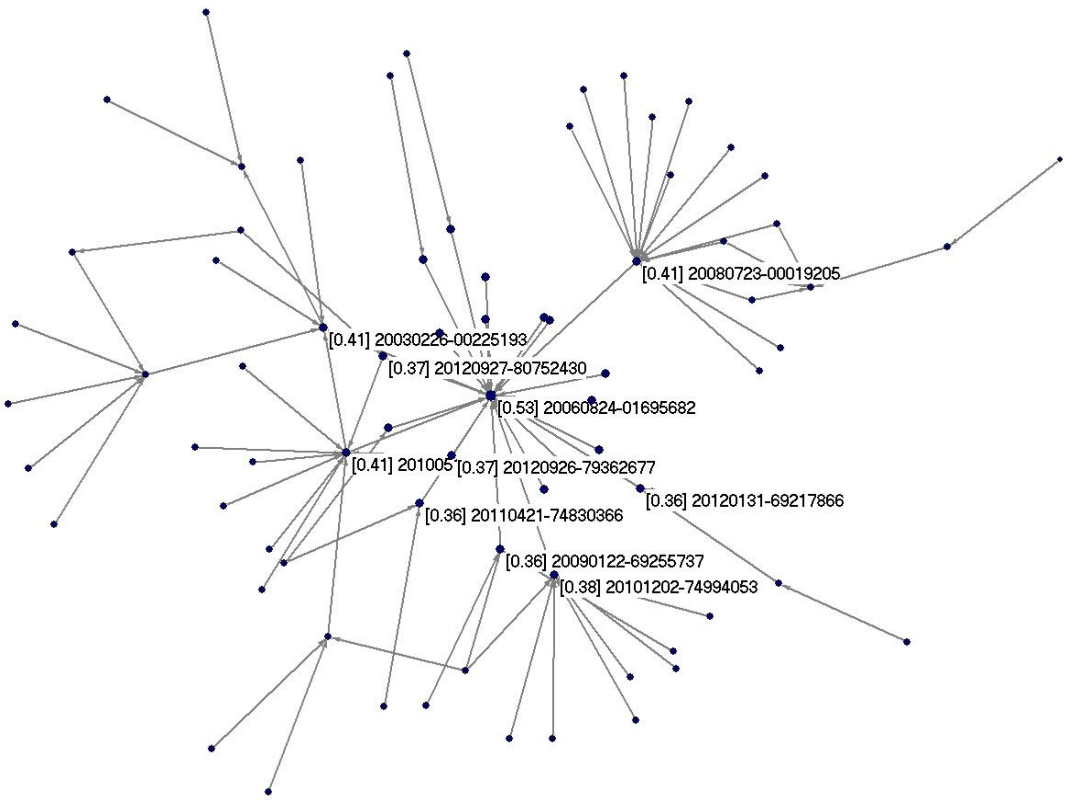

Figure 5.3.NP36. Closeness centrality of NP36

<u>*Authority weights (Figure 5.4.NP36, Table 5.10.NP36*</u>) – There are two authorities in NP36: The previously mentioned vertex 3, and vertex 9, published simultaneously in several countries by the British company Exitech Ltd, entitled 'Method and apparatus for laser beam alignment for solar panel scribing'.

Table 5.10.NP36. The authority patents of NP36

Rank	Vertex	Value	Id (Label)
1	9	0.97	20100512-73283052
2	3	0.24	20060824-01695682

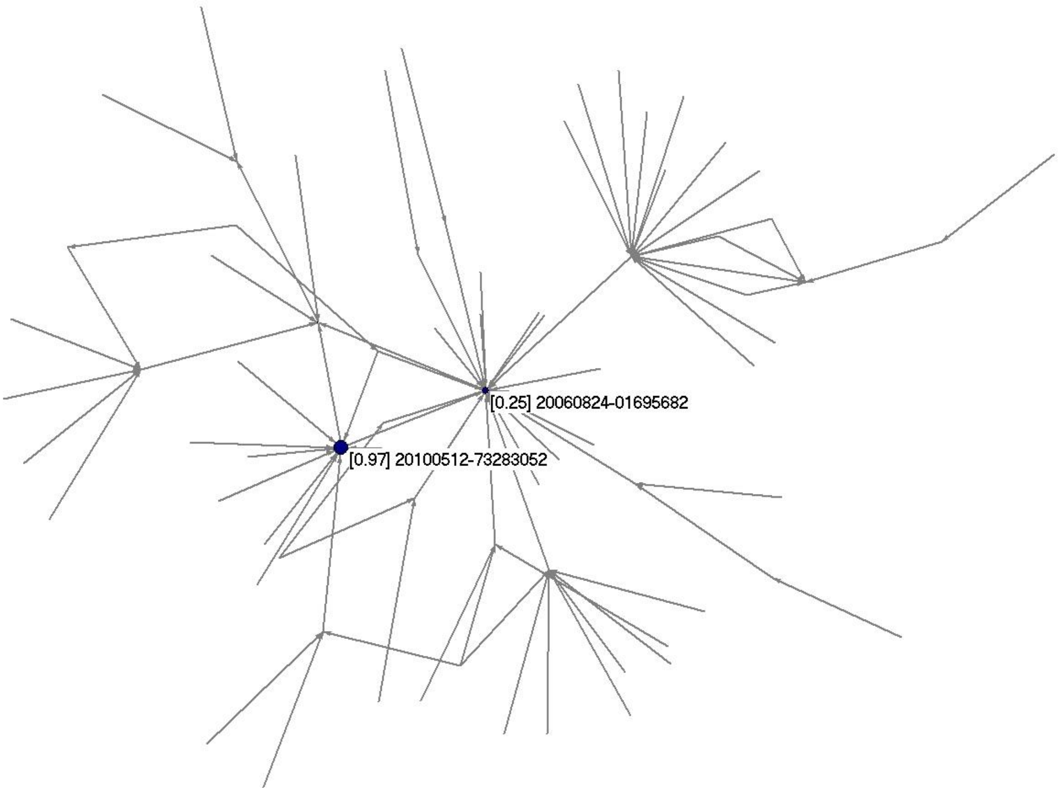

Figure 5.4.NP36. The authority patents of NP36

<u>*Hub weights (Figure 5.4.NP36, Table 5.11.NP36)*</u> – There are 10 hubs in NP36. The first five are:

- vertex 59, published in Germany by the German company Creotech GMBH, with the title ‘Safety clamp for PV modules and method for securing PV modules in an insertion system’;
- vertex 58, published in Europe by the German company Creotech GMBH, with the title ‘Safety clamp for PV modules and method for securing PV modules in an insertion system’;
- vertex 27, published in Germany by the company SFS Intec Holding AG, with the title ‘Connection holder for an upper fixing point of a suspended component’;
- vertex 45, published in Germany by the German company Sulfurcell Solartechnik GMBH, with the title, in the original language of ‘Klemmeinrichtung und Solarmoduleinheit’;
- vertex 21, published in Germany by the German company Rehau AG & Co., with the title ‘Multi-part frame for plate-shaped modules’.

Table 5.11.NP36. The hub patents of NP36

Rank	Vertex	Value	Id (Label)
1	59	0.36	20120927-80752430
2	58	0.36	20120926-79362677
3	27	0.32	20110804-77176873
4	45	0.32	20120209-78984403
5	21	0.32	20110505-76334141
6	40	0.32	20111201-78895370
7	37	0.32	20111118-74297298
8	74	0.32	20130102-77040541
9	72	0.32	20121206-81222313
10	9	0.04	20100512-73283052

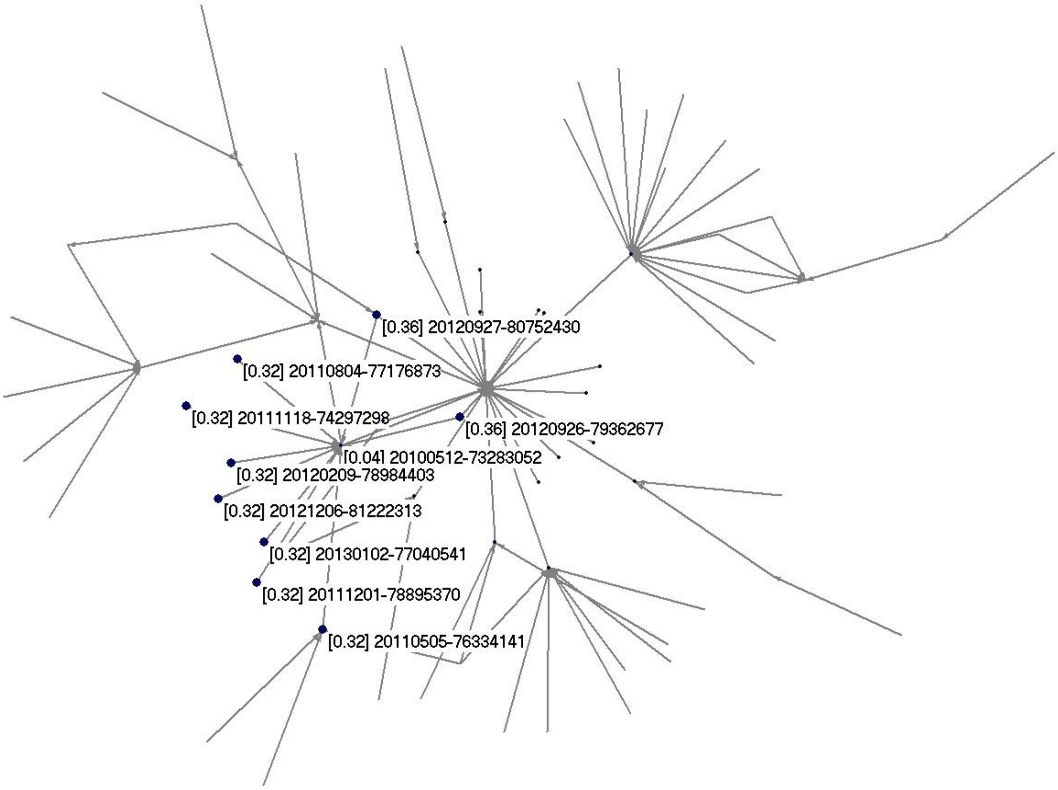

Figure 5.4.NP36. The hub patents of NP36

<u>*SPC (Figure 5.6.NP36, Table 5.12.NP36)*</u> – Figure 5.6.NP36 depicts the technological trajectory of NP36. It comprises six patents and goes from P36 to the most recent vertex 66, a patent published in Germany by Bosch GmbH, with the title, in the original language of 'Traganordnung für Solarmodule mit Biegesteg in der Aufnahmenut'.

Table 5.12.NP36. Vertices on main path SPC [flow] of NP36

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000927-21298078
2	2	1	20030226-00225193
3	59	1	20120927-80752430
4	3	1	20060824-01695682
5	9	1	20100512-73283052
6	66	1	20121121-79538640

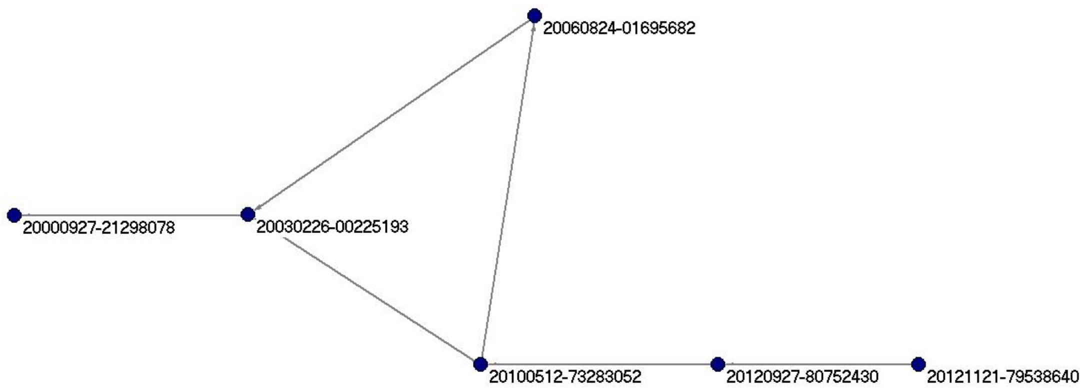

Figure 5.6.NP36. SPC of NP36

Network and connectivity analysis of network built on P37 (NP37)- 0000927-21298089

P37 is a European patent published by the Japanese Kaneka Corporation, with the title 'Photovoltaic generation system, wiring apparatus for photovoltaic generation system, and wiring structure therefor' (IPC: G05F1/67). NP37 characteristics are given in Table 5.7.NP37.

Table 5.7.NP37. Characteristics

Number of vertices (n)	**10**
	Arcs
Total number of lines	9
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.09
Average degree	1.80

In-degree centrality (Figure 5.1.NP37, Table 5.8.NP37) – P37 is the most cited patent of NP37.

Table 5.8.NP37. In-degree and out-degree centrality values of NP37

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	1 (37)	7	20000927-21298089	3	1	20110301-67484543
2	2	2	20031021-58041939	10	1	20120321-74590336
3				9	1	20111110-76493574
4				8	1	20111110-76493569
5				7	1	20110819-73694375
6				6	1	20110428-76464237
7				5	1	20110414-75502795
8				4	1	20110324-73850228
9				2	1	20031021-58041939
10				3	1	20110301-67484543

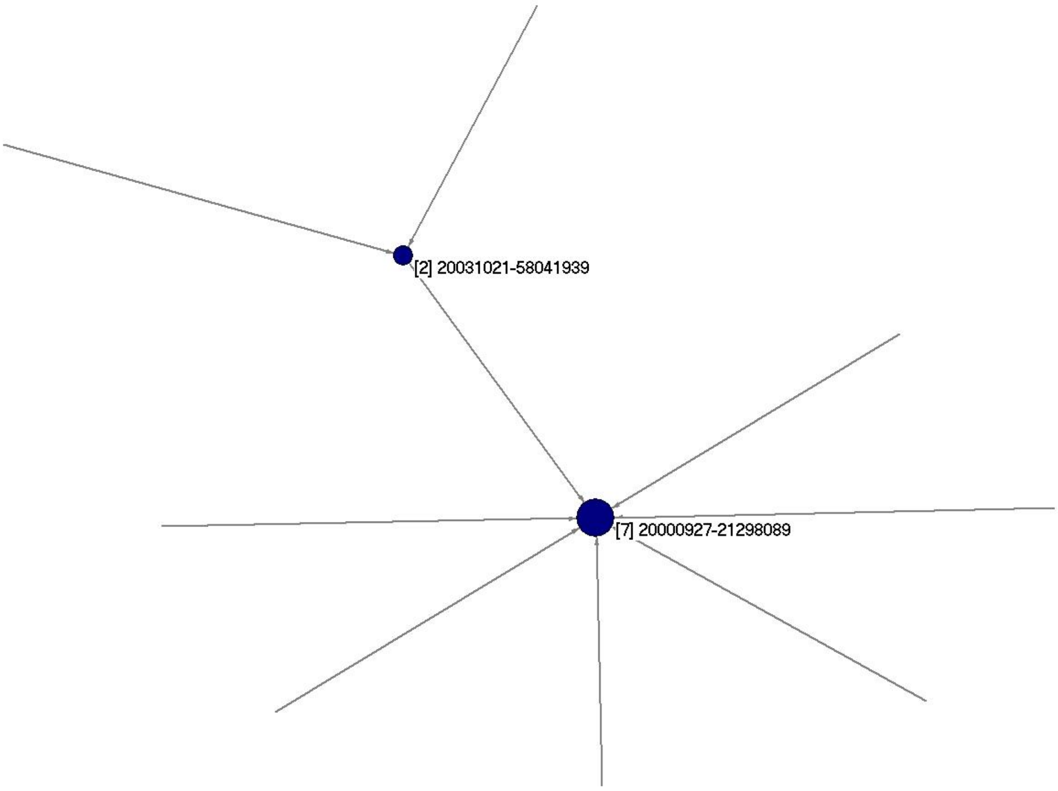

Figure 5.1.NP37. In-degree centrality of NP37

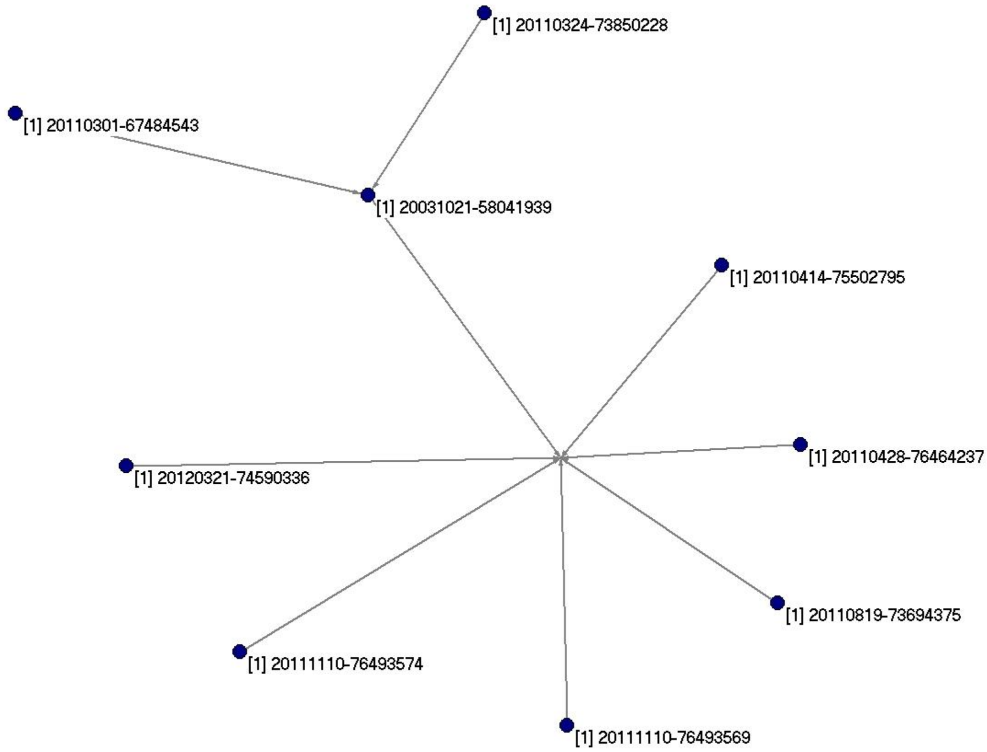

Figure 5.2.NP37. Out-degree centrality of NP37

<u>*Closeness centrality (Figure 5.3.NP37, Table 5.9.NP37)*</u> – P37 is the first among the top 10 patents for the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Fig. 6.3.NP37, which shows P37 lying at the centre of the surrounding clusters.

Table 5.9.NP37. Closeness centrality values of NP37

Rank	**Vertex**	**Value**	**Id (Label)**
1	1 (P37)	0.82	20000927-21298089
2	2	0.60	20031021-58041939
3	7	0.47	20110819-73694375
4	8	0.47	20111110-76493569
5	6	0.47	20110428-76464237
6	10	0.47	20120321-74590336
7	5	0.47	20110414-75502795
8	9	0.47	20111110-76493574
9	3	0.39	20110301-67484543
10	4	0.39	20110324-73850228

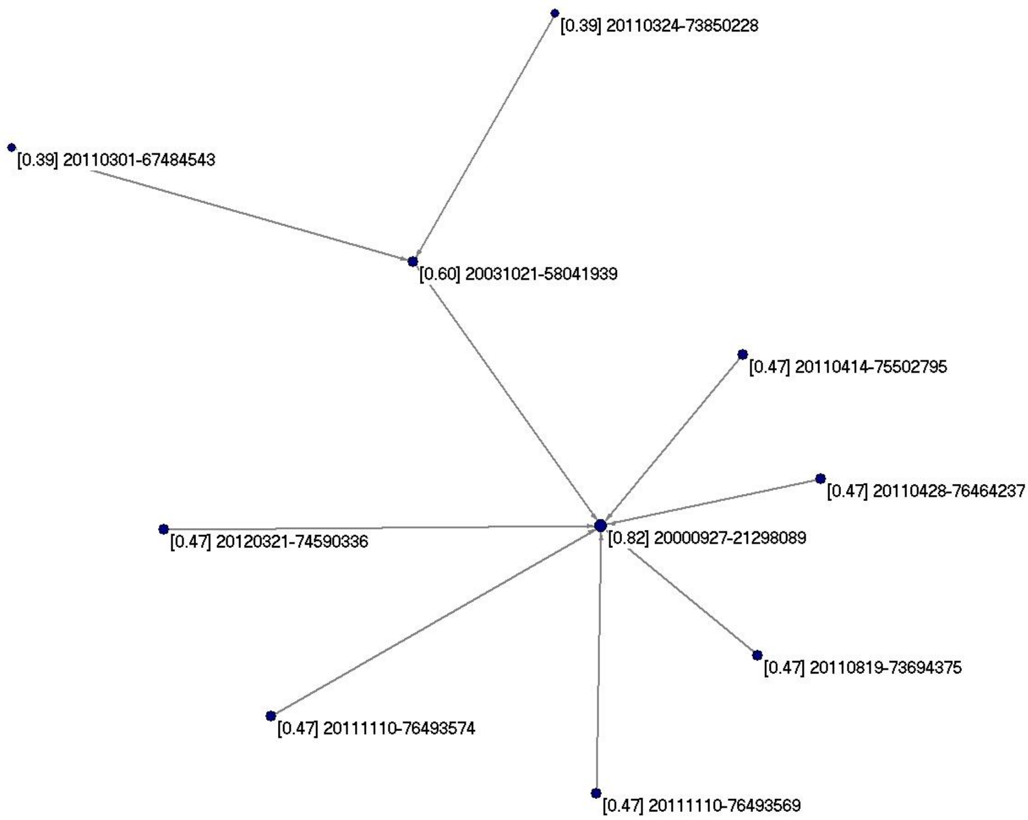

Figure 5.3.NP37. Closeness centrality of NP37

<u>*Authority weights (Figure 5.4.NP37, Table 5.10.NP37)*</u> – P37 is also the only authority of NP37.

Table 5.10.NP37. The authority patent of NP37

Rank	Vertex	Value	Id (Label)
1	1 (P37)	1	20000927-21298089

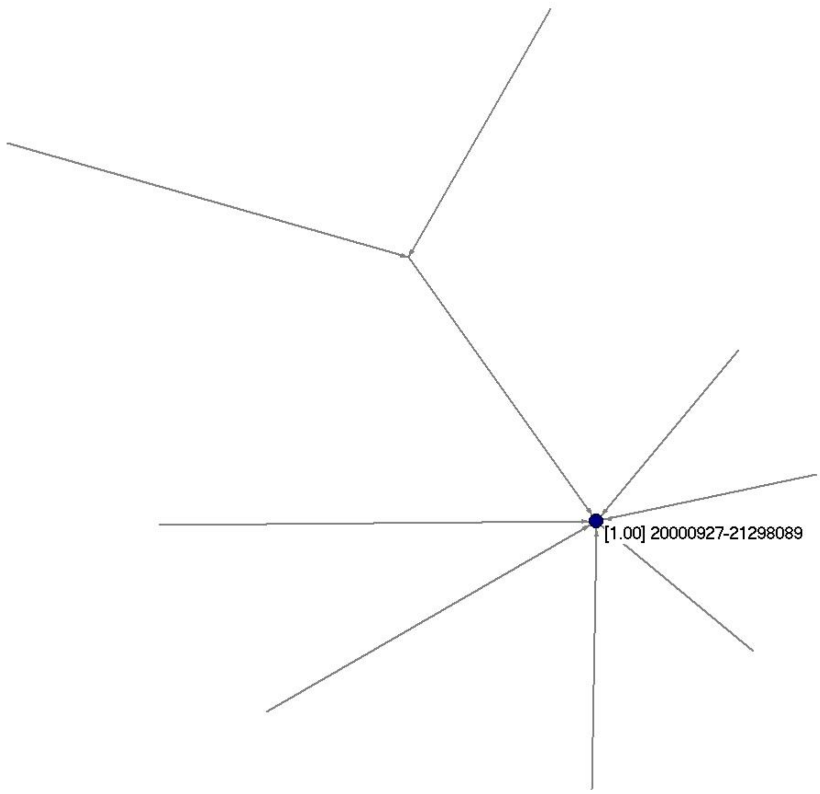

Figure 5.4.NP37. The authority patent of NP37

<u>Hub weights (Figure 5.4.NP37, Table 5.11.NP37)</u> – The top five hubs of NP37 are:

- vertex 7, published in France by the French company Cegelec Sud Est, with the title ‘Electrical installation for e.g. public usage building, has units switching direct current generating units between configuration and another configuration ensuring activation of direct current generating unit short-circuiting units’;
- vertex 10, published in Europe by the Belgian company MS Europe SPRL, with the title ‘Photovoltaic plant with protection against the risks of electrocution in the event of a fire and safety box for such a plant’;
- vertex 6, published simultaneously in several countries, by three private American inventors, with the title ‘Solar photovoltaic module safety shutdown system’;

- vertex 8, published simultaneously in several countries, by the German SMA Solar Technology Ag, with the title 'Method for limiting the generator voltage of a photovoltaic installation in case of danger and photovoltaic installation';
- vertex 2, published in the US by the American company Koninkl Philips Electronics, with the title 'Solar cell array having lattice or matrix structure and method of arranging solar cells and panels'.

Table 5.11.NP37. The hub patents of NP37

Rank	Vertex	Value	Id (Label)
1	7	0.38	20110819-73694375
2	10	0.38	20120321-74590336
3	6	0.38	20110428-76464237
4	8	0.38	20111110-76493569
5	2	0.38	20031021-58041939
6	5	0.38	20110414-75502795
7	9	0.38	20111110-76493574
8	4	0.38	20110324-73850228
9	3	0.38	20110301-67484543

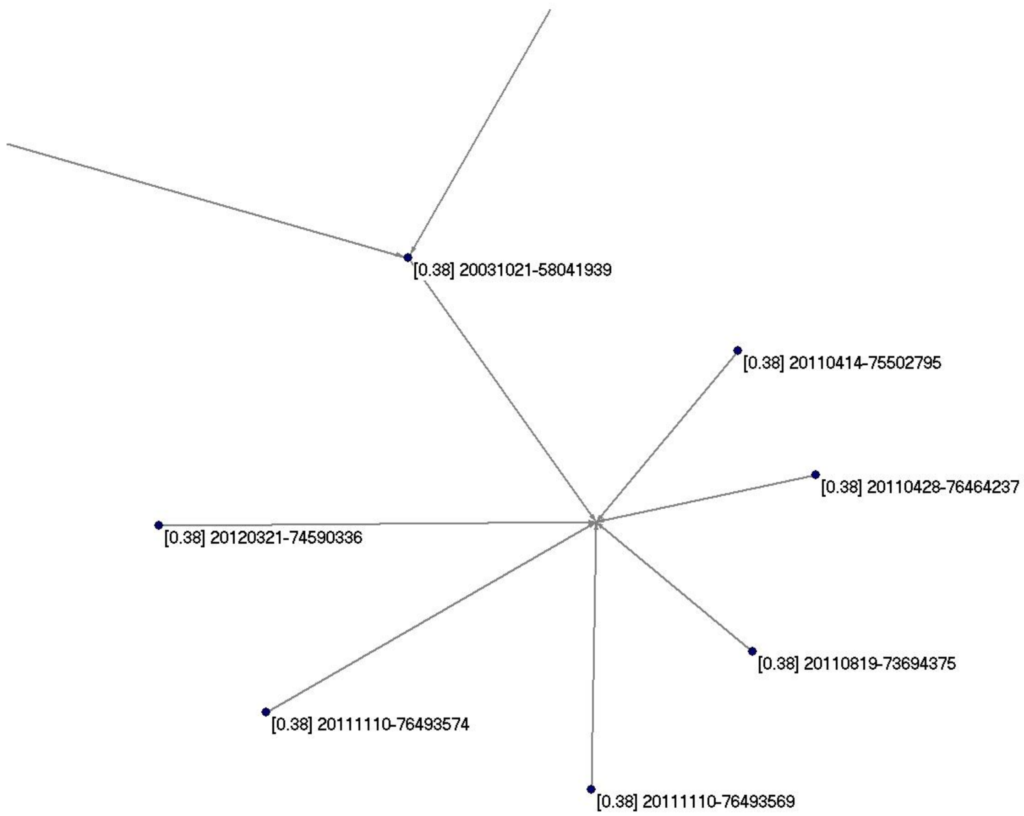

Figure 5.4.NP37. The hub patents of NP37

<u>*SPC (Figure 6.6.NP37, Table 5.12.NP37)*</u> – The technological trajectory of NP37 is depicted in Figure 5.6.NP37. This goes from P37 to the most recent patent (vertex 10) which was described as the second hub of NP37.

Table 5.12.NP37. Vertices on main path SPC [flow] of NP37

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000927-21298089
2	2	1	20031021-58041939
3	3	1	20110301-67484543
4	4	1	20110324-73850228
5	5	1	20110414-75502795
6	6	1	20110428-76464237
7	7	1	20110819-73694375
8	8	1	20111110-76493569
9	9	1	20111110-76493574
10	10	1	20120321-74590336

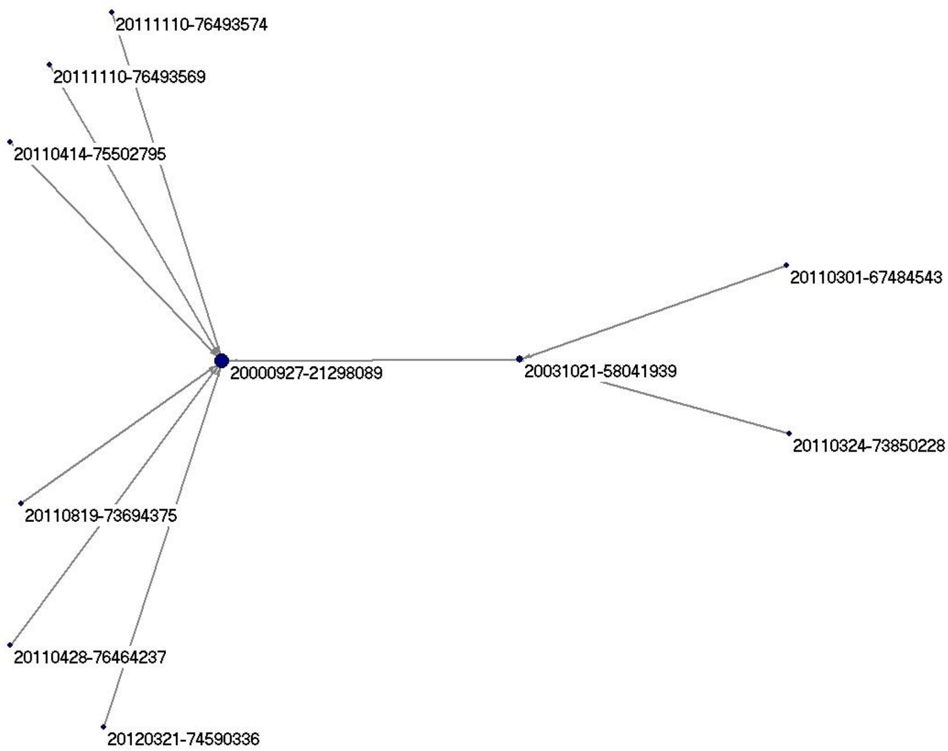

Figure 5.6.NP37. SPC of NP37

__Network and connectivity analysis of network built on P39 (NP39)- 20000607-21304993__

P39 is a European patent published by the German Pilikington Solar International GmbH, with the title 'Photovoltaic solar module in a plate form' (IPC: H01L31/042).

Table 5.7.NP39. Characteristics

Number of vertices (n)	**238**
	Arcs
Total number of lines	321
Number of loops	8
Number of multiple lines	26
Density [loops allowed]	0.00
Average degree	2.69

__In-degree centrality (Figure 5.1.NP39, Table 5.8.NP39)__ – The most cited patent of NP39 is vertex 5, published simultaneously in several countries, by the British company Powertile Ltd, with the title 'Photovoltaic tiles'. P39 is the second most cited patent.

Table 5.8.NP39 top 10 in-degree and out-degree centrality values of NP39

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	5	22	20021219-26472425	219	10	20121113-78039768
2	1 (P39)	17	20000607-21304993	59	4	20100722-73856832
3	13	12	20071025-17195767	214	3	20121025-80936569
4	15	11	20080124-17207809	192	3	20120802-80362911
5	69	11	20101102-73155016	178	3	20120606-79736738
6	82	10	20110308-74930119	80	3	20110210-74657098
7	17	10	20080508-21529884	78	3	20110204-73409967
8	52	9	20100512-73283052	155	3	20120329-79407826
9	8	9	20050202-18772436	147	3	20120301-79199318
10	14	8	20071115-21512101	140	3	20120202-78942613

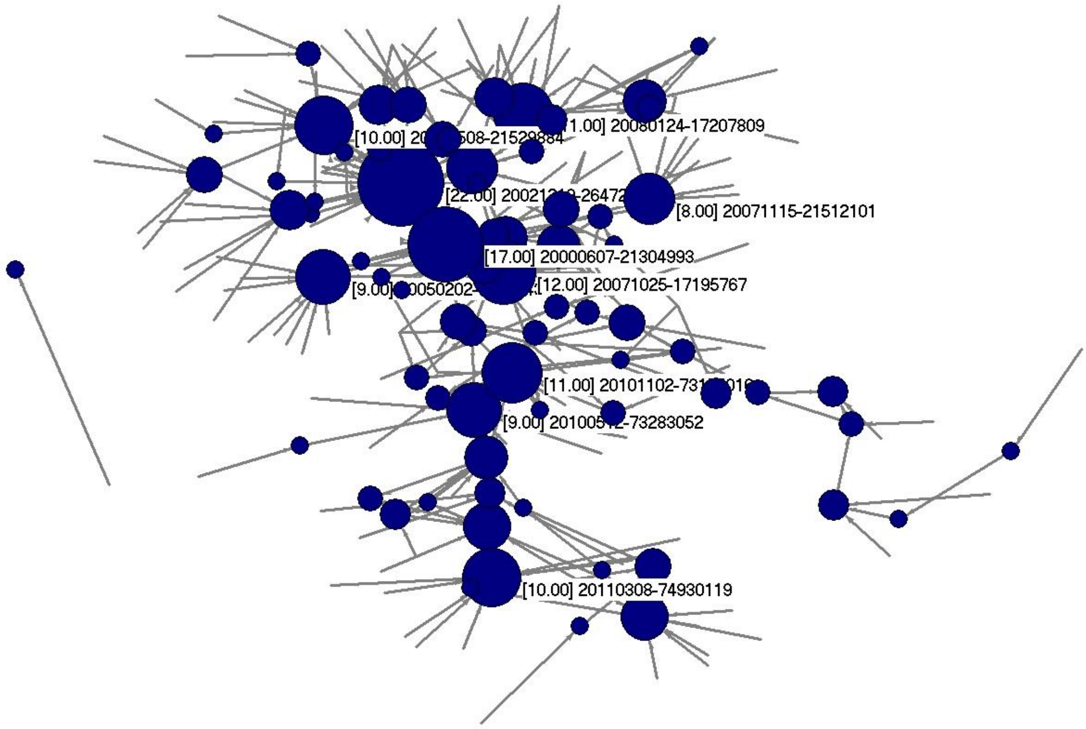

Figure 5.1.NP39. In-degree centrality of NP39

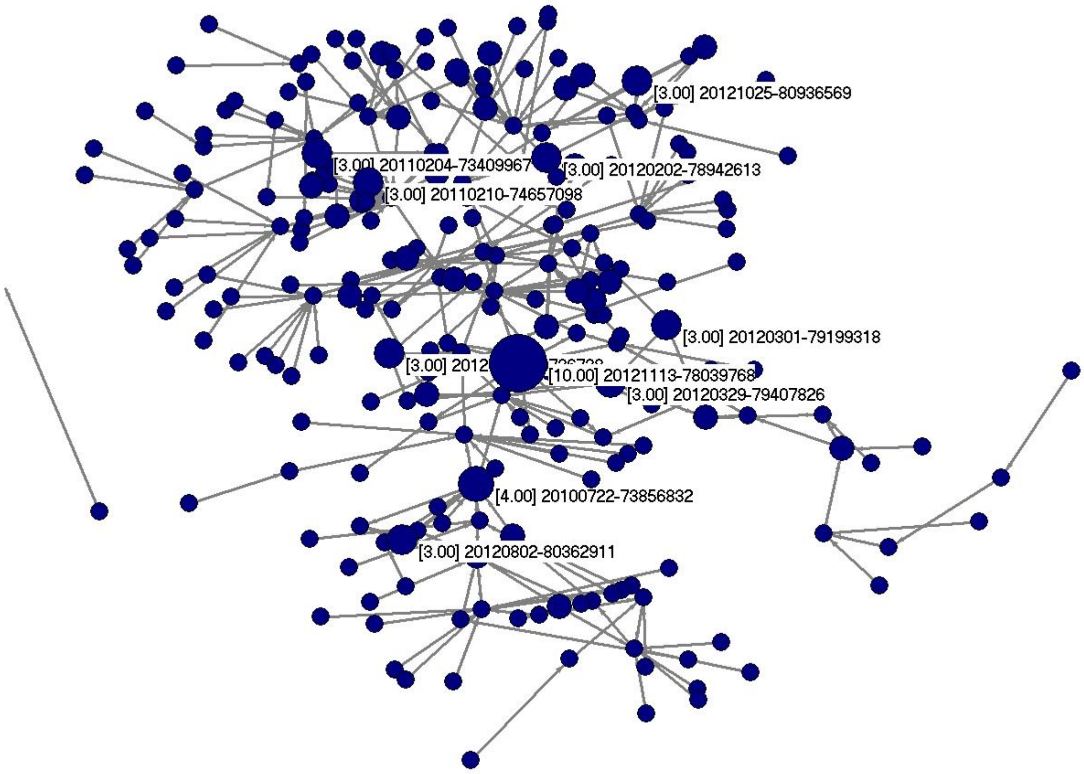

Figure 5.2.NP39. Out-degree centrality of NP39

Closeness centrality (Figure 5.3.NP39, Table 5.9.NP39) – P39 is the first among the top 10 patents for the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Fig. 6.3.NP39, which shows P39 lying at the centre of the surrounding clusters.

Table 5.9.NP39. Closeness centrality values of NP39

Rank	Vertex	Value	Id (Label)
1	1 (P39)	0.29	20000607-21304993
2	42	0.26	20100202-67289302
3	2	0.26	20020425-14968029
4	13	0.25	20071025-17195767
5	5	0.25	20021219-26472425
6	79	0.24	20110209-74208810
7	69	0.24	20101102-73155016
8	173	0.23	20120524-69123838
9	29	0.23	20091008-71339020
10	7	0.23	20031211-15075292

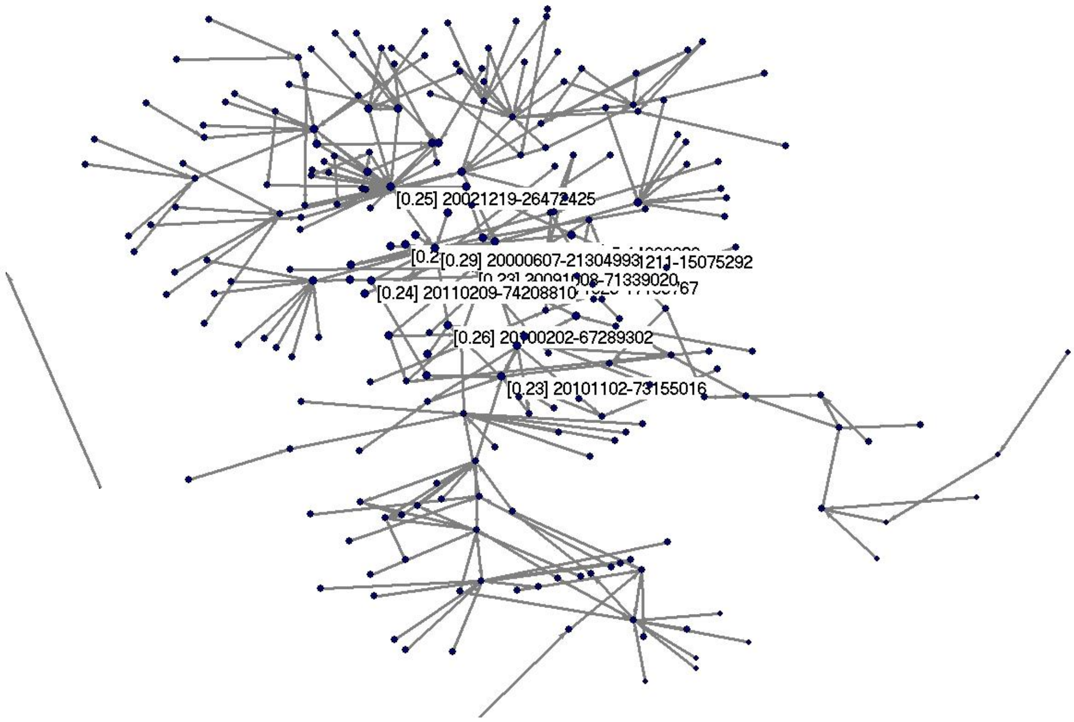

Figure 5.3.NP39. Closeness centrality of NP39

Authority weights (Figure 5.4.NP39, Table 5.10.NP39) – There are six authorities in NP39. The top five are:

- vertex 5, described as the most cited patent;
- vertex 17, published simultaneously in several countries by the Italian company Mind SRL, entitled 'Modular photovoltaic element for building roofs';
- vertex 20, published in France by a private inventor, entitled 'Photovoltaic panels connecting and fixing device for e.g. building, has support provided with rubber pads and circular lower hooks, and independent circular upper hook inserted in rail and blocked by detent device';
- vertex 6, published simultaneously in several different countries by two private inventors, entitled 'Construction products with integrated photovoltaics';
- vertex 11, published simultaneously in several different countries by the British company Powertile Ltd, entitled 'Solar tile assemblies'.

Table 5.8.NP39. The authority patents of NP39

Rank	Vertex	Value	Id (Label)
1	5	0.96	20021219-26472425
2	17	0.17	20080508-21529884
3	20	0.17	20090327-23646329
4	6	0.09	20030814-01704494
5	11	0.06	20060810-29425080
6	44	0.04	20100317-69950939

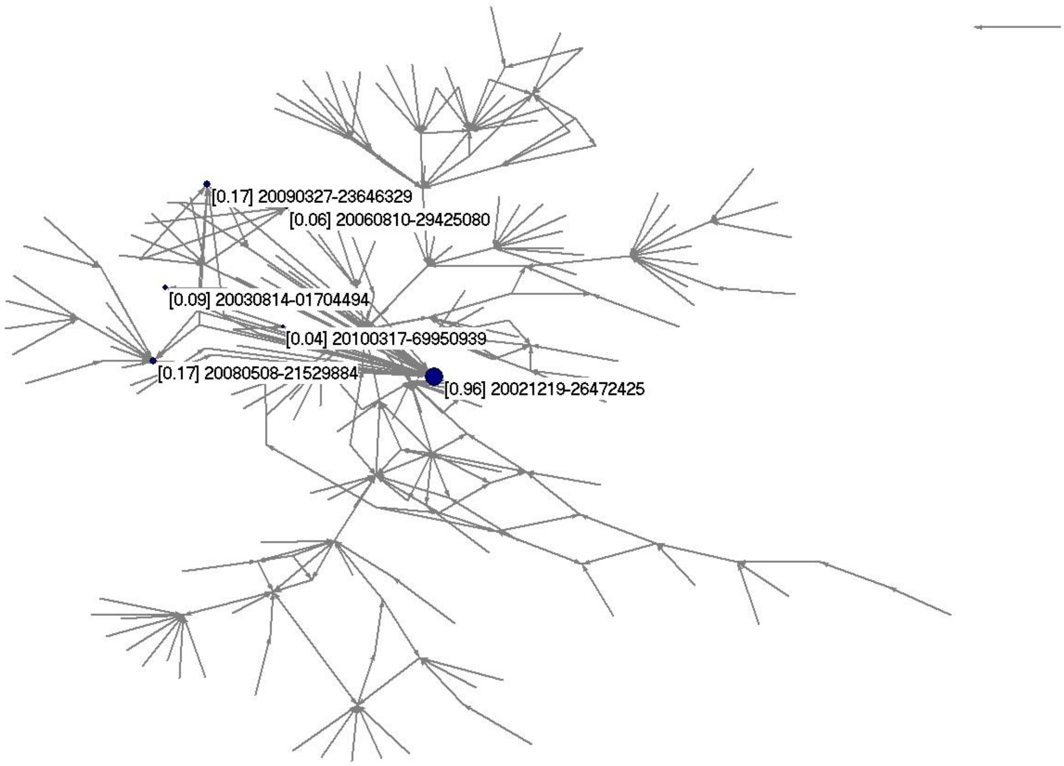

Figure 5.4.NP39. The authority patents of NP39

<u>*Hub weights (Figure 5.4.NP39, Table 5.11.NP39)*</u> – The top five hub patents in NP39 are:

- vertex 80, published simultaneously in several countries by a private French inventor, entitled 'Device for fixing photovoltaic panels onto roof tiles, improved so as to be able to be positioned via the outside of the roofing';
- vertex 78, published in France by a private inventor, entitled 'Dispositif permettant de fixer des pennaux photovoltaiques des tuiles de toit, emrliore de maniere a pouvoir eitre pose par l'exterieur de la toiyure';
- vertex 65, published in Europe, by the above French inventor, but with a different title 'Device for fixing photovoltaic panels on roof tiles';
- vertex 49, published in Europe, by the Singaporean company Dragon Energy, entitled 'Photovoltaic tile';

- vertex 45, published in Europe by the Japanese Zeon Corporation, entitled 'Nitrile rubber composition, crosslinked nitrile rubber composition, crosslinked rubber material and method for producing nitrile rubber composition'.

Table 5.11.NP39. The hub patents of NP39

Rank	Vertex	Value	Id (Label)
1	80	0.27	20110210-74657098
2	78	0.27	20110204-73409967
3	65	0.24	20100915-70050485
4	49	0.22	20100428-69950932
5	45	0.22	20100317-70307653
6	21	0.21	20090415-69280809
7	121	0.21	20111011-73086631
8	27	0.20	20090529-70539727
9	26	0.20	20090522-70446502
10	6	0.20	20030814-01704494

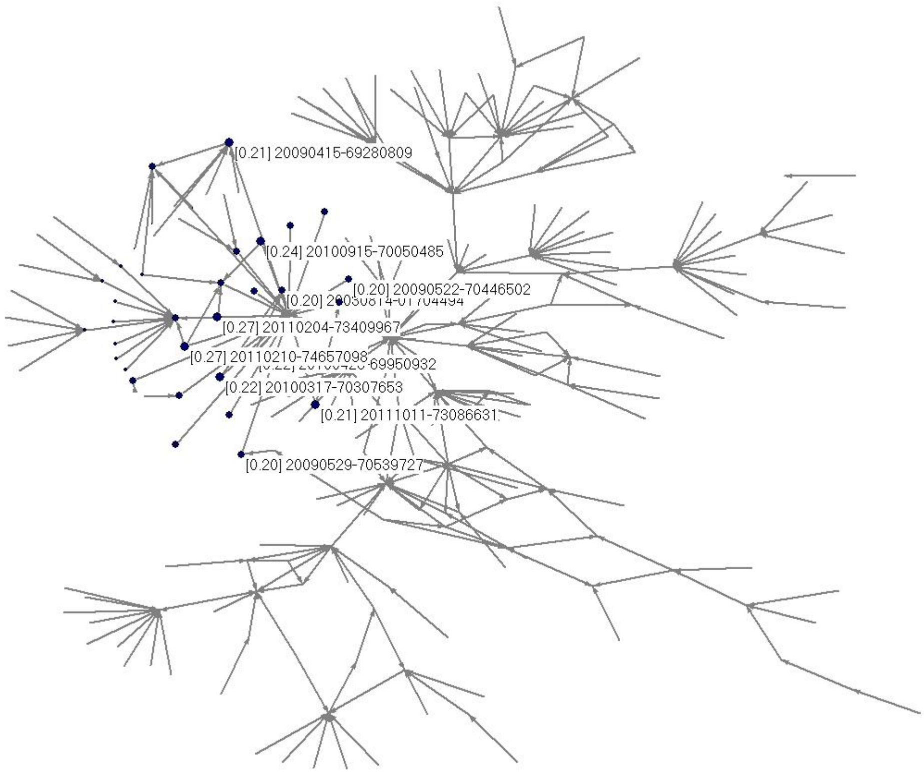

Figure 5.4.NP39. The hub patents of NP39

<u>*SPC (Figure 5.6.NP39, Table 5.12.NP39)*</u> – NP39 has three strong components, which we shrank to apply the SPC algorithm. Figure 5.6.NP39 depicts the technological trajectory of

NP39 characterized by 33 patents. It goes from P39 to a German patent (vertex 207) published by a private inventor, entitled ‘Vorrichtung zum Kühlen eines Solarmoduls’.

Table 5.12.NP39. Vertices on main path SPC [flow] of NP39

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000607-21304993
2	7	1	20031211-15075292
3	47	1	20100415-73310311
4	165	1	20120628-79079045
5	34	1	20091203-71780493
6	126	1	20111103-76617364
7	5	1	20021219-26472425
8	11	1	20060810-29425080
9	21	1	20090415-69280809
10	101	1	20110630-75726662
11	98	1	20110623-73207350
12	137	1	20120117-58857259
13	69	1	20101102-73155016
14	219	1	20121113-78039768
15	147	1	20120301-79199318
16	42	1	20100202-67289302
17	13	1	20071025-17195767
18	104	1	20110705-71792073
19	64	1	20100902-74387668
20	155	1	20120329-79407826
21	166	1	20120424-79327262
22	146	1	20120223-79140661
23	2	1	20020425-14968029
24	203	1	20120920-79172640
25	10	1	20060309-17102887
26	15	1	20080124-17207809
27	48	1	20100422-73144562
28	67	1	20101021-74939643
29	170	1	20120517-76185618
30	141	1	20120209-77180540
31	139	1	20120201-77046836
32	205	1	20120921-81083269
33	207	1	20120926-76208481

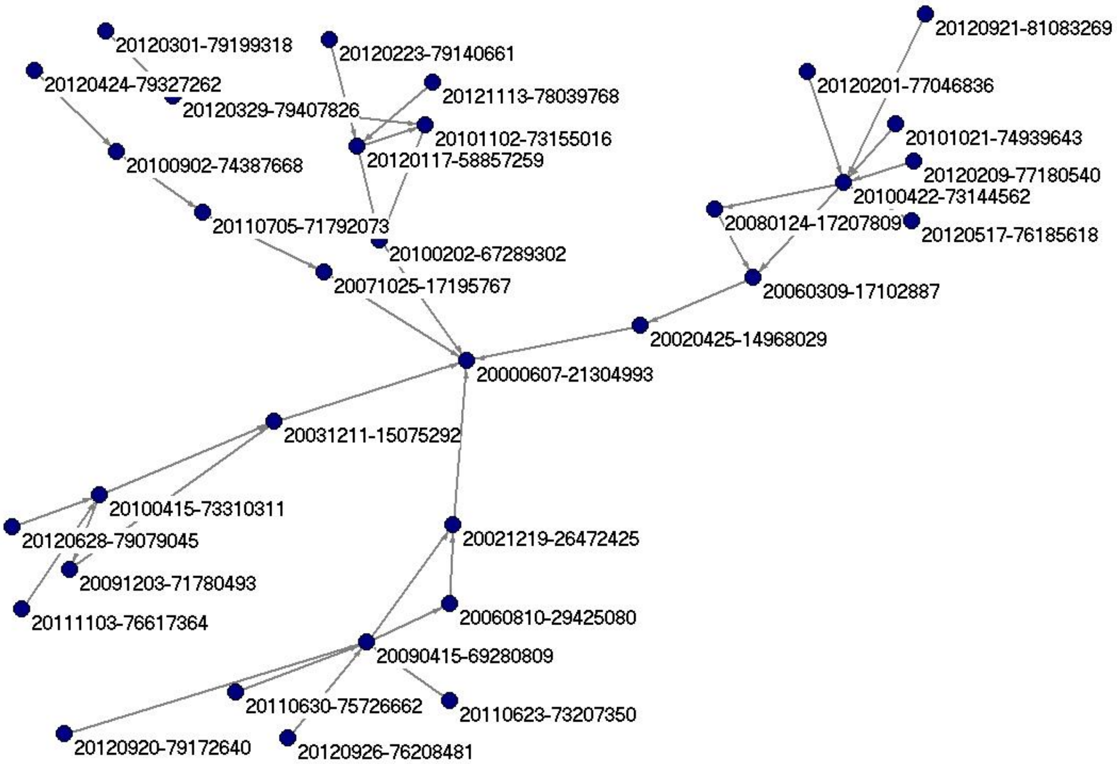

Figure 5.6.NP39. SPC of NP39

Network and connectivity analysis of network built on P40 (NP40)- 20001004-21306878

P40 is a European patent published by the Japanese Kaneka Corporation with the title 'Photovoltaic module and power generation system' (IPC: E04D13/18). NP40 characteristics are given in Table 5.7.NP40.

Table 5.7.NP40. Characteristics

Number of vertices (n)	**65**
	Arcs
Total number of lines	97
Number of loops	6
Number of multiple lines	17
Density [loops allowed]	0.02
Average degree	2.98

<u>*In-degree centrality (Figure 5.1.NP40, Table 5.8.NP40)*</u> – P40 is the third most cited patent in NP40, the most cited patent (vertex 5) was published in Europe by the German Spelsberg Guenther GmbH, entitled 'Junction box for a solar cell module'.

Table 5.8.NP40. Top 10 in-degree and out-degree centrality values of NP40

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	5	13	20060621-18791559	63	6	20121113-78039768
2	21	8	20091117-71146995	53	5	20120329-79407826
3	1 (P40)	7	20001004-21306878	31	2	20110106-75606264
4	16	6	20081009-17251006	59	2	20120724-79595572
5	29	4	20100902-74387668	56	2	20120626-76379281
6	59	3	20120724-79595572	50	2	20120301-79199318
7	27	3	20100610-73586223	38	2	20111011-73585972
8	35	3	20110616-76868845	33	2	20110426-73390846
9	15	2	20081002-17251003	58	1	20120710-78814954
10	3	2	20060221-58307780	57	1	20120628-79079045

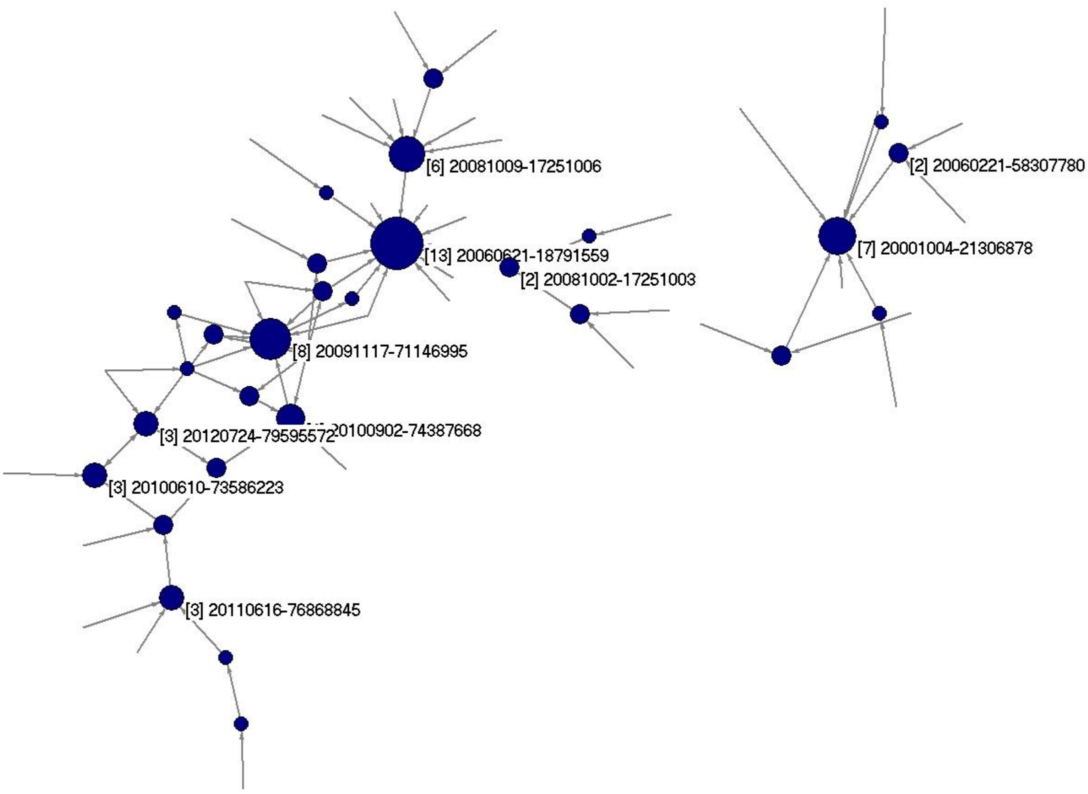

Figure 5.1.NP40. In-degree centrality of NP40

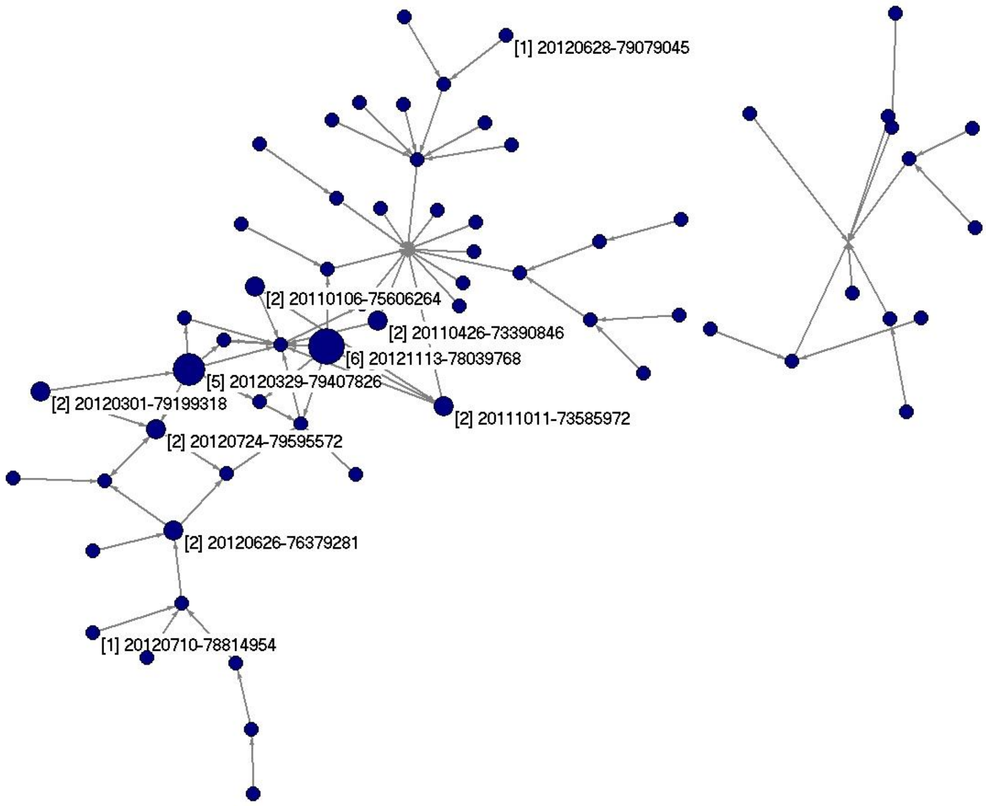

Figure 5.2.NP40. Out-degree centrality of NP40

<u>*Closeness centrality (Figure 5.3.NP40, Table 5.9.NP40)*</u> – According to the closeness centrality measure, the European patent (vertex 5) is ranked 1st among the top 10 patents. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Fig. 6.3.NP40, which shows vertex 5 lying at the centre of the surrounding clusters.

Table 5.9.NP40. Closeness centrality values of NP40

Rank	Vertex	Value	Id (Label)
1	5	0.26	20060621-18791559
2	38	0.25	20111011-73585972
3	9	0.25	20080814-00095838
4	33	0.25	20110426-73390846
5	21	0.25	20091117-71146995
6	45	0.24	20120117-58857259
7	63	0.24	20121113-78039768
8	29	0.22	20100902-74387668
9	31	0.21	20110106-75606264

10	16	0.21	20081009-17251006

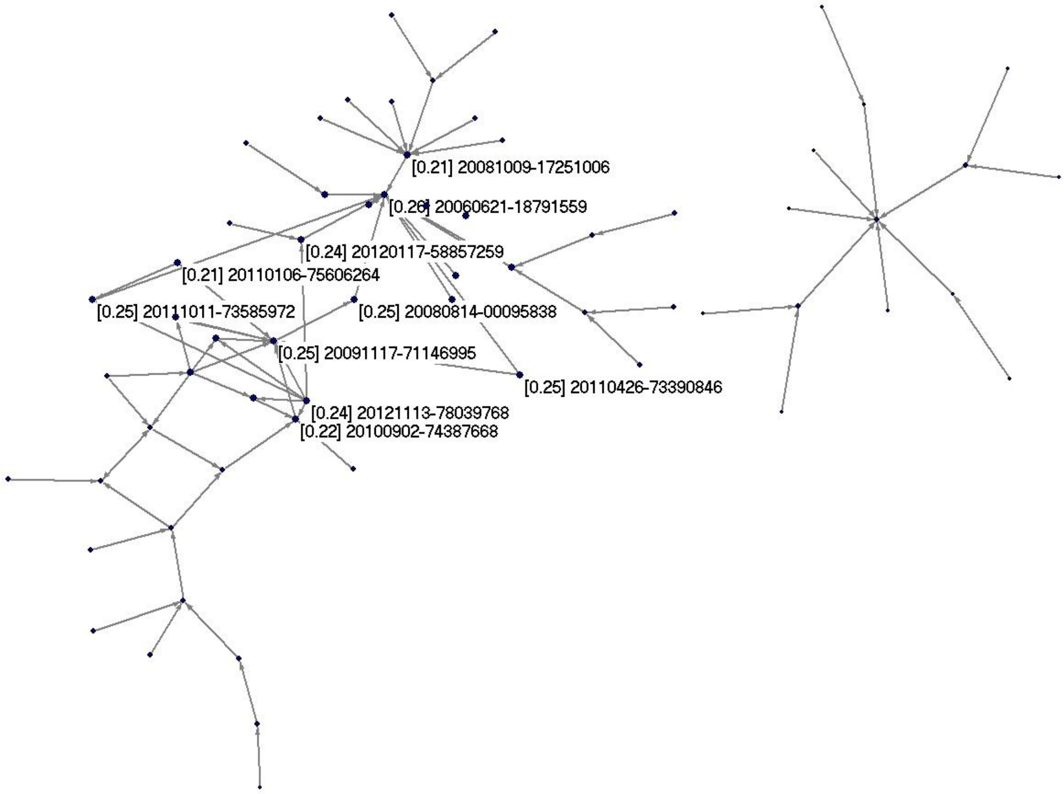

Figure 5.3.NP40. Closeness centrality of NP40

<u>*Authority weights (Figure 5.4.NP40, Table 5.10.NP40)*</u> – There are eight authorities in NP40. The top five are:

- vertex 53, published in the US by the Tyco Electronics Corporation, entitled 'Contact rail for a junction box';
- vertex 59, published in the US by the American Solarbridge Technologies, entitled 'System and apparatus for interconnecting and array of power generating assemblies';
- vertex 21, published in the US by the German Kostal Industrie Elektrik GmbH, entitled 'Electrical connection and junction box for a solar cell module';
- vertex 38, published in the US by the American Phoenix Contact Corporation, entitled 'Connection and junction box for a solar module';

- vertex 55 , published in the US by the Taiwan company Delta Electronics, entitled 'Junction box and conductor strip connector device thereof'.

Table 5.10.NP40. The authority patents of NP40

Rank	Vertex	Value	Id (Label)
1	53	0.98	20120329-79407826
2	59	0.22	20120724-79595572
3	21	0.03	20091117-71146995
4	38	0.02	20111011-73585972
5	55	0.02	20120424-79327262
6	54	0.02	20120410-74510972
7	5	0.02	20060621-18791559
8	60	0.01	20120821-76056874

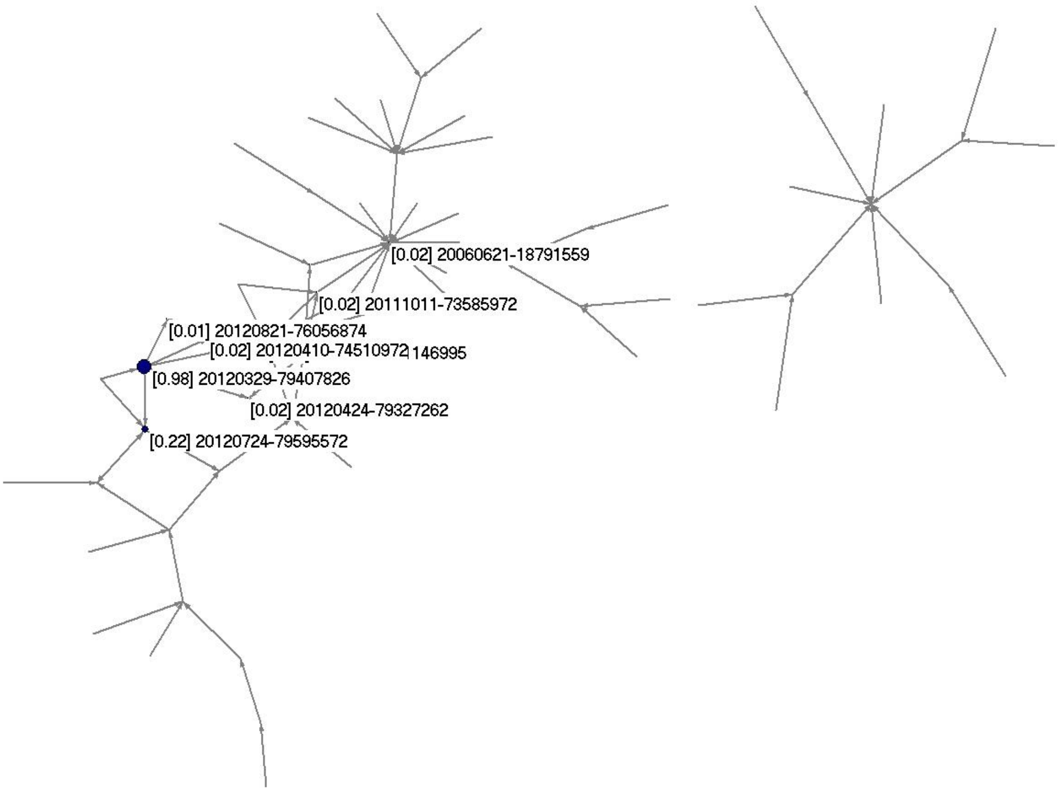

Figure 5.4.NP40. The authority patents of NP40

<u>*Hub weights (Figure 5.6.NP40, Table 5.11.NP40)*</u> – There are five hub patents in NP40:

- vertex 50, published in the US, by the Chinese company Hon Hai Precision Industry Co. Ltd, entitled 'Background of the invention';

- vertex 53, which is also described as the first authority in N40;
- vertex 27, published in the US by the American company Enphase Energy, with the title 'Mounting rail and power distribution system for use in a photovoltaic system';
- vertex 63, published in the US by the German company Tyco Electronics, entitled 'Connecting device for connection to a solar module and solar module with such a connecting device';
- vertex 31, published in the US by the German company Tyco Electronics, entitled 'Junction Box For Connecting A Solar Cell, Electrical Diode, Guiding Element And Fixing Means.

Table 5.11.NP40. The hub patents of NP40

Rank	Vertex	Value	Id (Label)
1	50	1	20120301-79199318
2	53	0.06	20120329-79407826
3	27	0.04	20100610-73586223
4	63	0.02	20121113-78039768
5	31	0.01	20110106-75606264

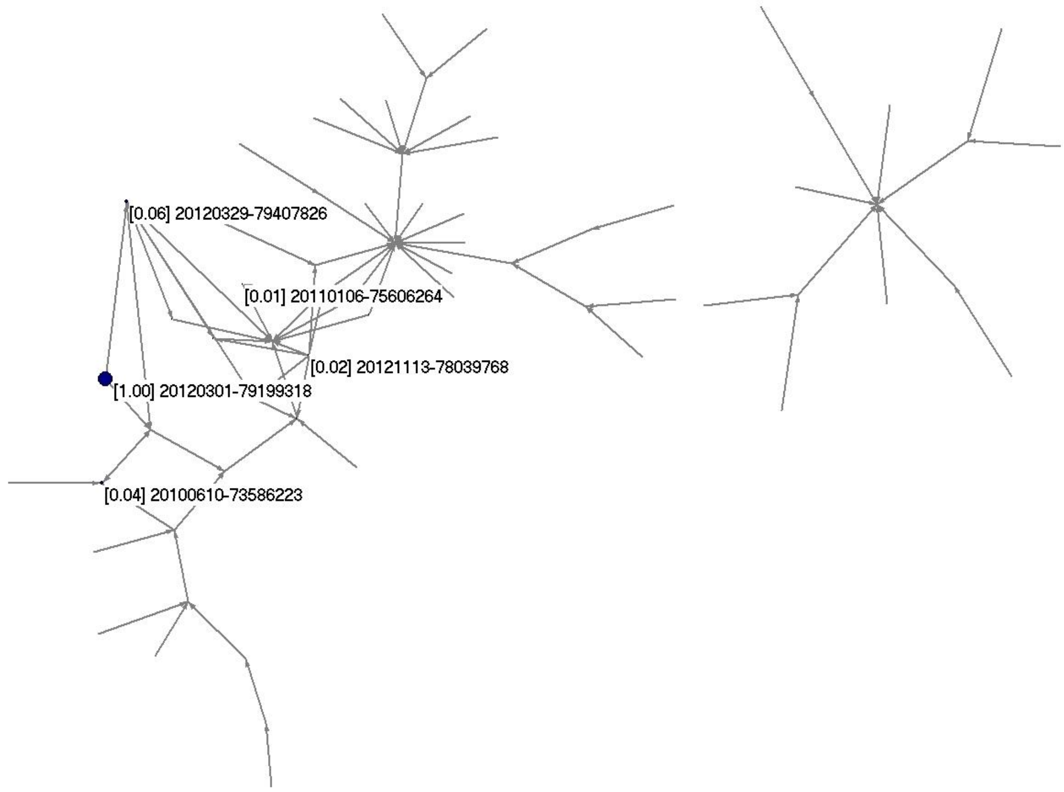

Figure 5.4.NP40. The hub patents of NP40

<u>*SPC (Figure 5.6.NP40, Table 5.12.NP40)*</u> – There are strong components in technological trajectory of NP40 comprises eight patents and goes from vertex 2 to the most recent vertex 60, described earlier as the last authority in NP40.

Table 5.12.NP40. Vertices on main path SPC [flow] of NP40

Rank	**Vertex**	**Cluster**	**Id (Label)**
1	2	1	20060621-18791559
2	9	1	20080814-00095838
3	21	1	20091117-71146995
4	29	1	20100902-74387668
5	54	1	20120410-74510972
6	55	1	20120424-79327262
6	53	1	20120329-79407826
7	50	1	20120301-79199318
8	60	1	20120821-76056874

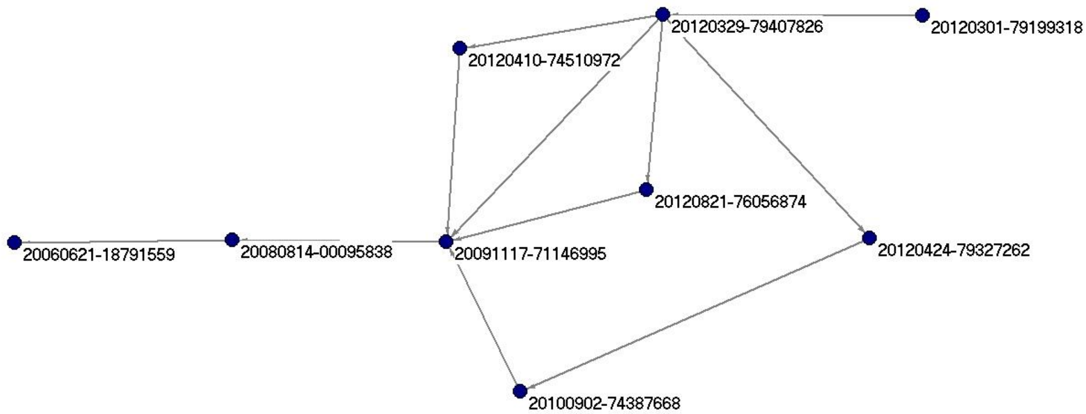

Figure 5.6.NP40. SPC of NP40

Network and connectivity analysis of network built on P41 (NP41)- 20000607-21307176

NP41 is the European patent published by the Japanese Canon Corporation, with the title 'Solar cell roof structure and construction method thereof' (IPC: E04D13/18). NP41 characteristics are given in Table 5.7.NP41.

Table 5.7.NP41. Characteristics

Number of vertices (n)	**1999**
	Arcs
Total number of lines	422
Number of loops	6
Number of multiple lines	146
Density [loops allowed]	0.00
Average degree	0.42

In-degree centrality (Figure 5.1.NP41, Table 5.8.NP41) – P41 is the seventh most cited patent in NP41. The most cited is (vertex 3) was published in the US, by eight private Japanese inventors, entitled 'Solar cell roof structure, construction method thereof, photovoltaic power generating apparatus, and building'.

Table 5.8.NP41. Top 10 in-degree and out-degree centrality values of NP41

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	3	33	20030610-63821714	173	15	20121030-72592977
2	4	21	20060824-01695682	28	7	20100722-73856832
3	5	14	20080723-00019205	154	6	20120802-80362911
4	25	10	20100512-73283052	36	6	20100930-74621952
5	51	10	20110308-74930119	185	4	20121121-79538640
6	20	9	20100225-72682175	20	4	20100225-72682175
7	1 (P41)	8	20000607-21307176	89	3	20111103-78041250
8	45	8	20101202-74994053	171	3	20121010-81179550
9	28	7	20100722-73856832	166	3	20120920-80743073
10	36	7	20100930-74621952	40	3	20101026-72030361

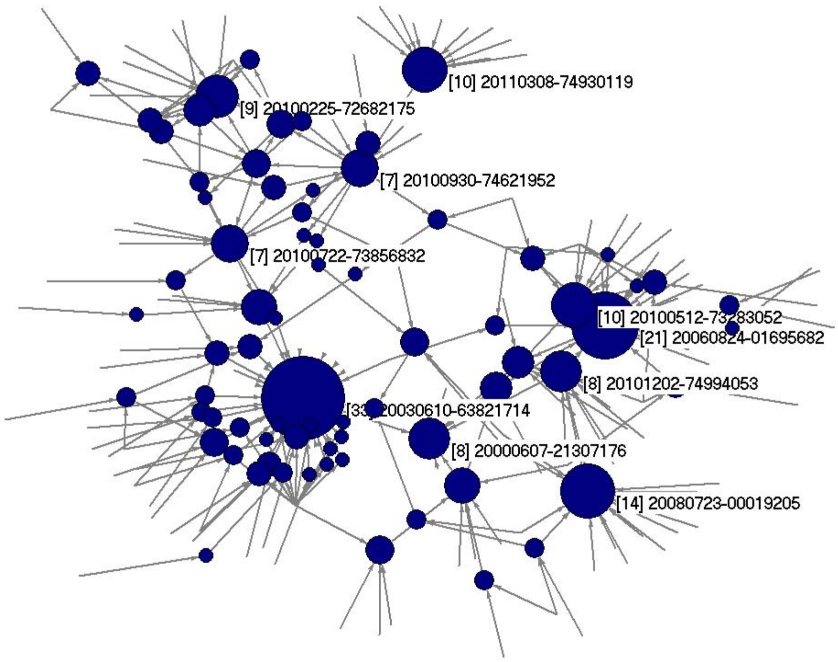

Figure 5.1.NP41. In-degree centrality of NP41

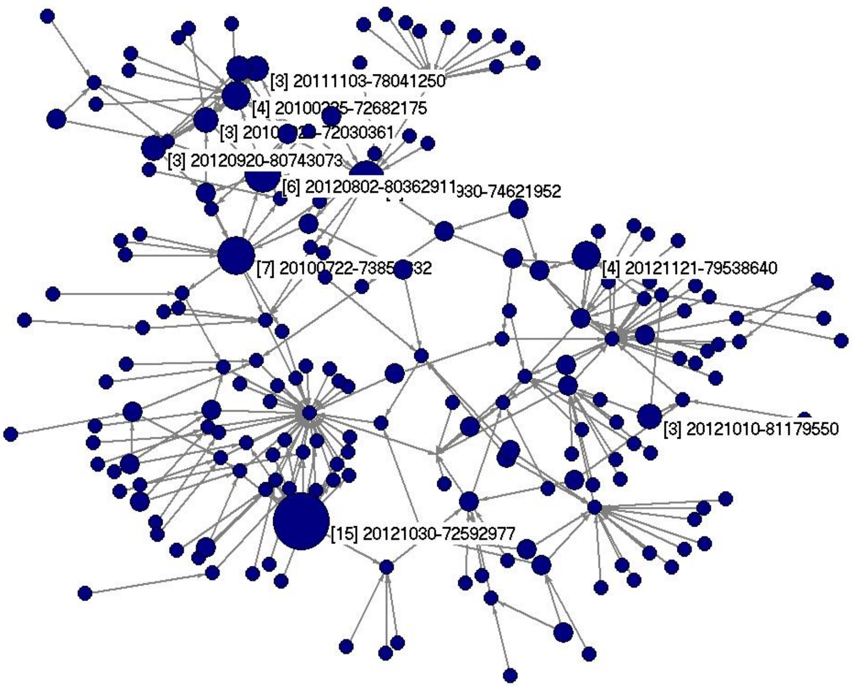

Figure 5.2.NP41 out-degree centrality of NP41

<u>*Closeness centrality (Figure 5.3.NP41, Table 5.9.NP41)*</u> – According to the closeness centrality measure 10 patents have the same value (0.03). This means that there is no one patent closes to the centre and to the others, and all 10 are relatively close to all the others. Among them are P41, and vertex 3, already mentioned as the most cited patent according to the in-degree centrality measure.

Table 5.9.NP41. Closeness centrality values of NP41

Rank	**Vertex**	**Value**	**Id (Label)**
1	3	0.03	20030610-63821714
2	1 (P41)	0.03	20000607-21307176
3	14	0.03	20090915-67924818
4	45	0.03	20101202-74994053
5	32	0.03	20100831-70515138
6	4	0.03	20060824-01695682
7	184	0.03	20121121-79538639
8	15	0.03	20100120-00053739
9	2	0.03	20030226-00225193
10	105	0.03	20120110-66567808

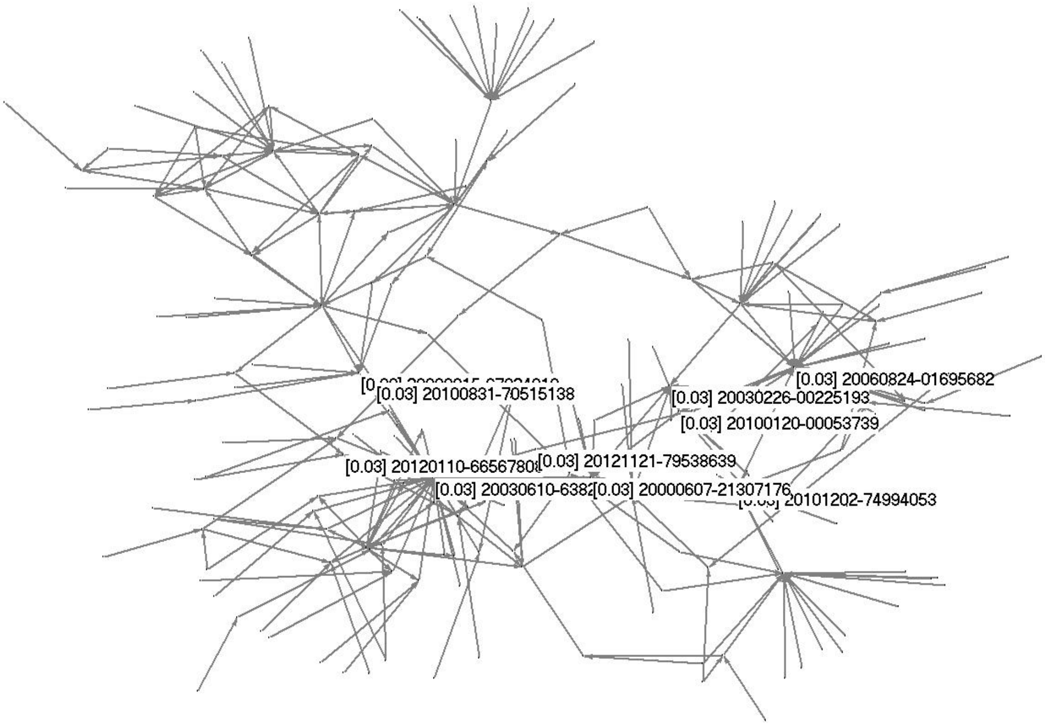

Figure 5.3.NP41 closeness centrality of NP41

<u>*Authority weights (Figure 5.4.NP41, Table 5.10.NP41)*</u> – There are 10 authority patents in NP41. The first has the highest value (0.99), followed by the other 9 with smaller values. They are:

- vertex 20, published in the US by the American company Socore Energy, with the title 'Solar panel support module and method for creating array of interchangeable and substitutable solar panel support modules';
- vertex 36, published in the US by the American Certateed Corporation, entitled 'Photovoltaic systems, methods for installing photovoltaic systems, and kits for installing photovoltaic systems';
- vertex 40, published in the US by the American company Solar Red Systems, entitled 'Plug and play solar panel assembly';

- vertex 28, published in the US by American Certain Teed Corporation, entitled 'Photovoltaic roof covering';
- vertex 130, published in the US by an American private inventor, entitled 'Structural insulated monolithic photovoltaic solar-power roof and method of use thereof'.

Table 5.10.NP41. The authority patents of NP41

Rank	Vertex	Value	Id (Label)
1	20	0.99	20100225-72682175
2	36	0.10	20100930-74621952
3	40	0.07	20101026-72030361
4	28	0.04	20100722-73856832
5	130	0.04	20120426-79560608
6	143	0.04	20120607-79843171
7	153	0.03	20120802-80362908
8	154	0.01	20120802-80362911
9	166	0.01	20120920-80743073
10	128	0.01	20120419-79507077

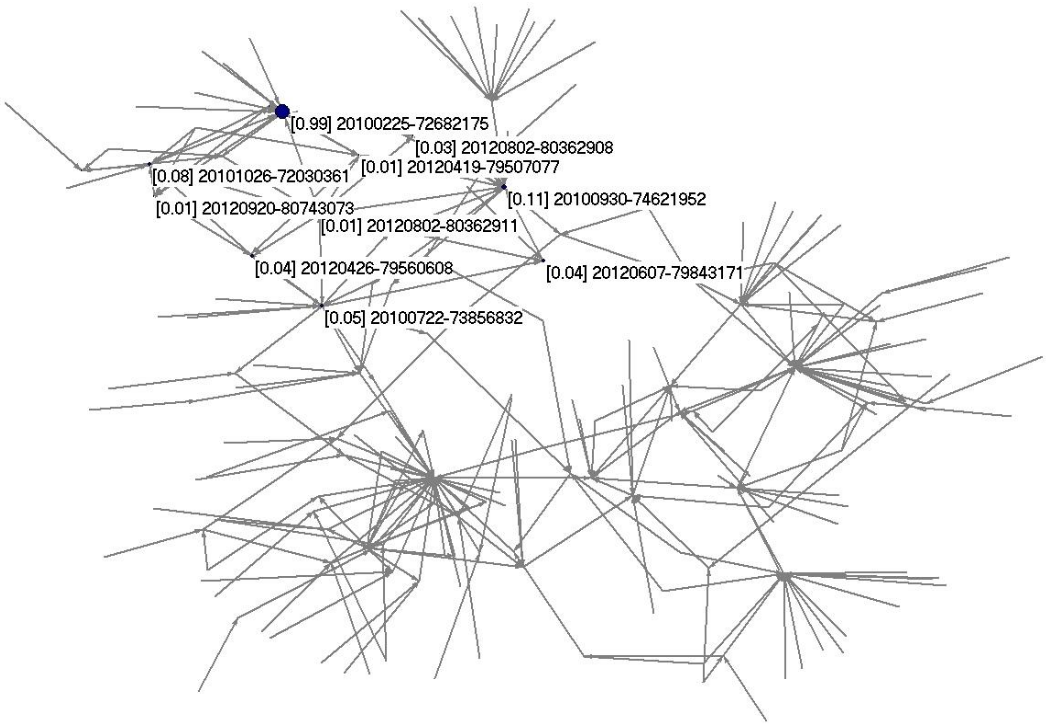

Figure 5.4.NP41. The authority patents of NP41

Hub weights (Figure 5.4.NP41, Table 5.11.NP41) – The top five hubs in NP41 are:

- vertex 155, published in the US by the German company Solon, entitled 'Solar installation including at least one solar module having a spring – loaded mounting of cover plate';
- vertex 115, published in Italy by the Italian company M. System SNC, with the original title 'Struttura modulare di sostegno per pannelli fotovoltaici';
- vertex 112, published simultaneously in several different countries by two private American inventors, entitled 'Electrical interconnects for photovoltaic modules and method thereof';
- vertex 101, published in Europe by the German company Solon, entitled 'Supporting plate for holding solar modules on a flat substrate and supporting plate array';
- vertex 80, published simultaneously in several different countries, by the German company Poeppelman Holding GMBH, entitled 'Solar module supporting module, solar module supporting structure and solar installation'.

Table 5.11.NP41. The hub patents of NP41

Rank	Vertex	Value	Id (Label)
1	155	0.41	20120807-74317070
2	115	0.39	20120311-75409607
3	112	0.39	20120209-79083331
4	101	0.39	20111214-76599314
5	80	0.39	20110922-76208080
6	145	0.39	20120614-79907276
7	154	0.16	20120802-80362911
8	89	0.15	20111103-78041250
9	40	0.07	20101026-72030361
10	166	0.04	20120920-80743073

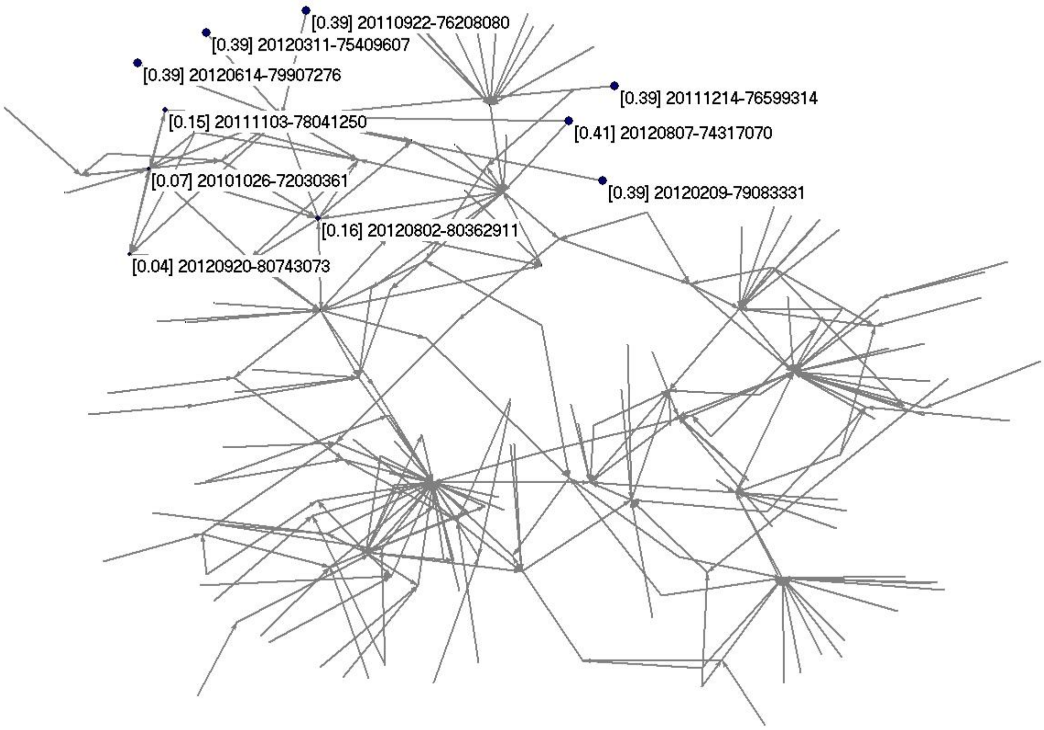

Figure 5.4.NP41. The hub patents of NP41

<u>*SPC (Figure 5.6.NP41, Table 5.12.NP41)*</u> – The technological trajectory of NP41 is comprised of eight patents and goes from P41 to the most recent patent (vertex 182), published in the US by the American Cadence Systems, entitled 'Method and system for optimally placing and assigning interfaces in a cross-fabric design environment'.

Table 5.12.NP41. Vertices on main path SPC [flow] of NP41

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000607-21307176
2	2	1	20030226-00225193
3	25	1	20100512-73283052
4	169	1	20120927-80752430
5	70	1	20110623-76894135
6	4	1	20060824-01695682
7	15	1	20100120-00053739
8	182	1	20121120-76895266

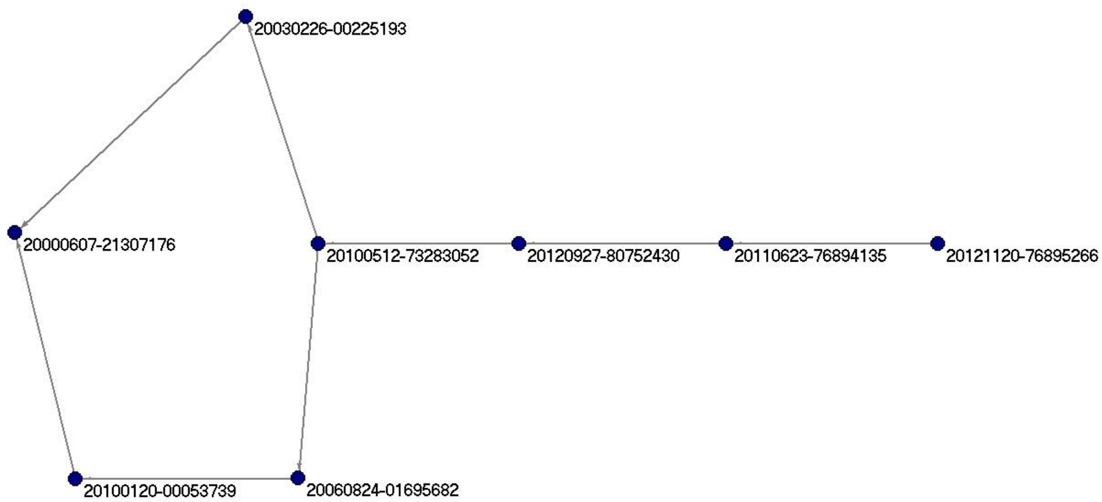

Figure 5.6.NP41. SPC of NP41

<u>Network and connectivity analysis of network built on P42 (NP42)- 20000913-21316396</u>

P42 is European owned by the Cooperatief advise en Onderzoek, with the title 'Cover system for arranging on a surface one or more solar elements such as solar panels and/or solar thermal collectors' (IPC: E04D13/18; F24J2/52; H01L31/042). NP42 characteristics are given in Table 5.7.NP42.

Table 5.7.NP42. Characteristics

Number of vertices (n)	**294**
	Arcs
Total number of lines	532
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.00
Average degree	3.61

In-degree centrality (Figure 5.1.NP42, Table 5.8.NP42) – According to the in-degree centrality measure, P42 is the most cited patent in NP42, with 41 citations.

Table 5.8.NP42. Top 10 in-degree and out-degree centrality values of NP42

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	1 (P42)	41	20000913-21316396	52	22	20100722-73856832
2	11	27	20070102-67218880	66	17	20100930-74621952
3	12	25	20070220-59281860	40	12	20100225-72682175
4	7	24	20050426-59281764	242	9	20120802-80362911
5	19	22	20081014-64287073	143	9	20111103-78041250
6	16	19	20080212-58734869	287	9	20121218-76247966
7	40	16	20100225-72682175	69	8	20101026-72030361
8	53	14	20100727-73875633	202	7	20120426-79560608
9	52	12	20100722-73856832	208	6	20120508-73149521
10	199	12	20120419-79507077	204	6	20120501-75971719

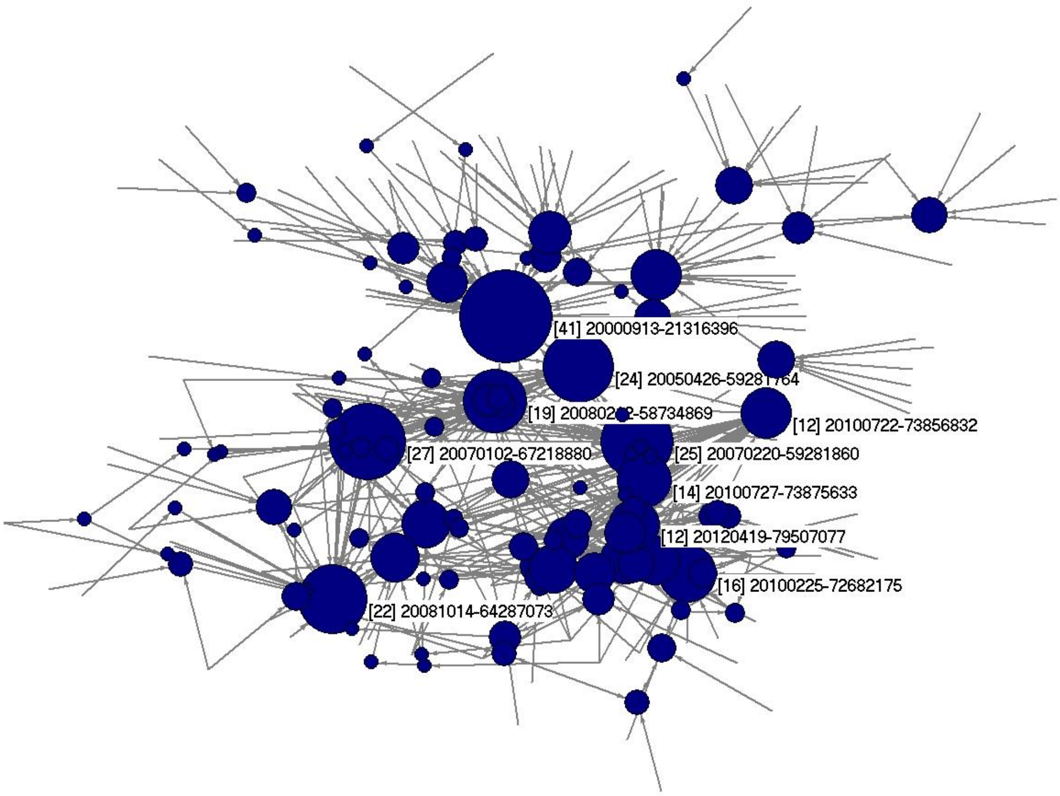

Figure 5.1.NP42. In-degree centrality of NP42

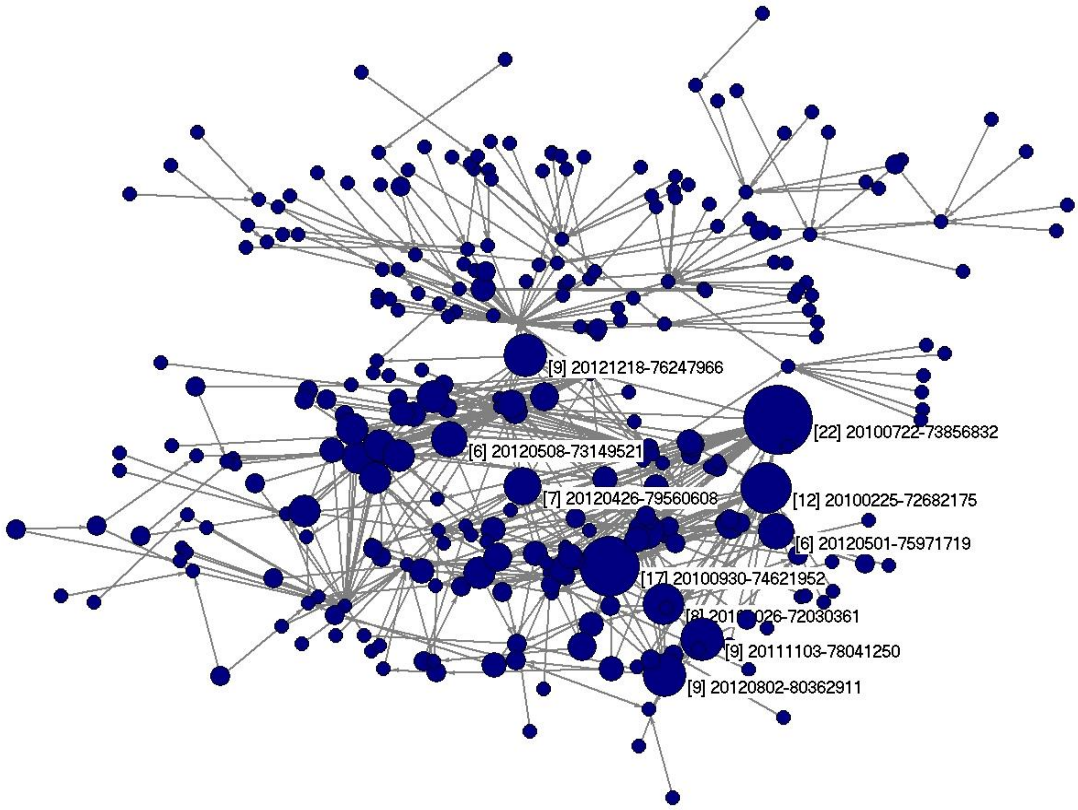

Figure 5.2.NP42. Out-degree centrality of NP42

<u>Closeness centrality (Figure 5.3.NP42, Table 5.9.NP42)</u> – According to the closeness centrality measure, the first position is occupied by vertex 7, published in the US by the American Powerlight Corporation, entitled 'Shingle system and method'. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP42, which shows vertex 7 lying at the centre of the surrounding clusters. P42 is ranked 2nd for closeness centrality.

Table 5.9.NP42. Closeness centrality values of NP42

Rank	Vertex	Value	Id (Label)
1	7	0.39	20050426-59281764
2	1 (P42)	0.38	20000913-21316396
3	12	0.38	20070220-59281860
4	16	0.36	20080212-58734869
5	52	0.35	20100722-73856832
6	66	0.33	20100930-74621952

7	202	0.33	20120426-79560608
8	11	0.32	20070102-67218880
9	53	0.32	20100727-73875633
10	287	0.32	20121218-76247966

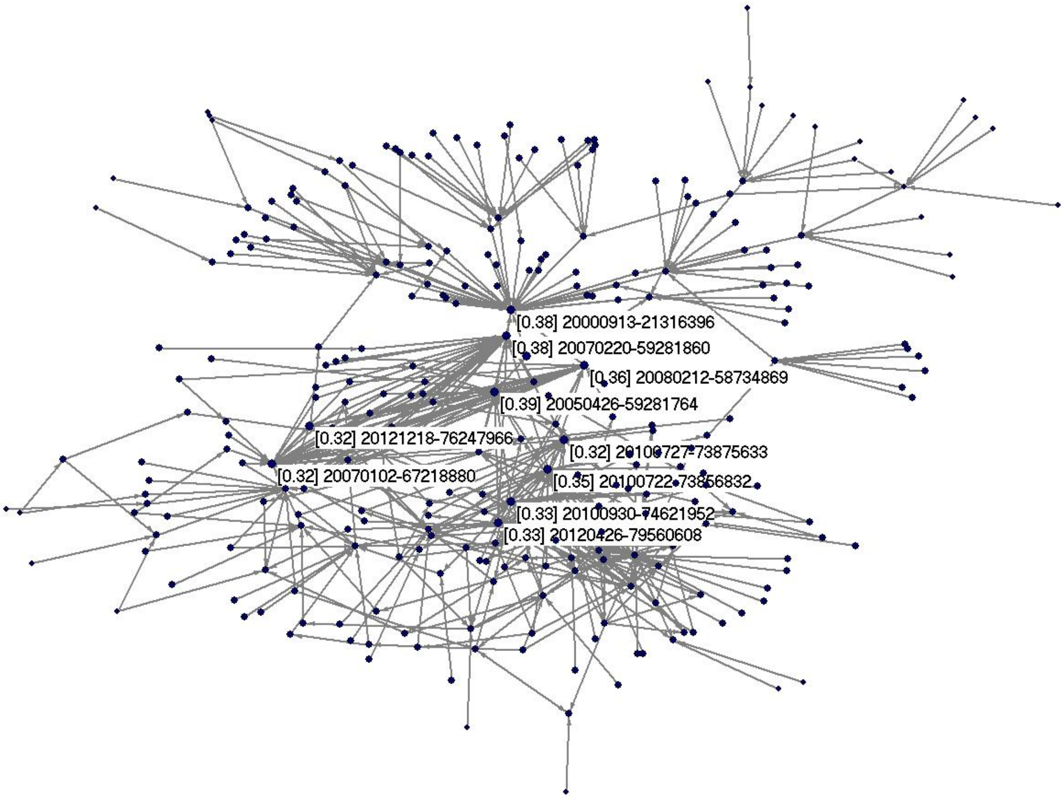

Figure 5.3.NP42. Closeness centrality of NP42

<u>*Authority weights (Figure 5.4.NP42, Table 5.10.NP42)*</u> – The top five authority patents in NP42 are:

- vertex 40, published in the US by the American company Socore Energy, with the title ‘Solar panel support module and method for creating array of interchangeable and substitutable solar panel support modules’;
- vertex 66, published in the US by the American CertainTeed Corporation, entitled ‘Photovoltaic systems, methods for installing photovoltaic systems, and kits for installing photovoltaic systems’;

- vertex 52, published in the US by the American CertainTeed Corporation, entitled ‘Photovoltaic roof system’;
- vertex 69, published in the US by the American company Solar Red System, entitled ‘Plug and play solar system’;
- vertex 223, published in the US by a private inventor, entitled ‘Photovoltaic systems, methods for installing photovoltaic systems, and kits for installing photovoltaic systems’.

Table 5.10.NP42. The authority patents of NP42

Rank	Vertex	Value	Id (Label)
1	40	0.99	20100225-72682175
2	66	0.12	20100930-74621952
3	52	0.06	20100722-73856832
4	69	0.05	20101026-72030361
5	223	0.03	20120607-79843171
6	202	0.03	20120426-79560608
7	260	0.03	20120920-80743073
8	241	0.02	20120802-80362908
9	199	0.02	20120419-79507077
10	242	0.01	20120802-80362911

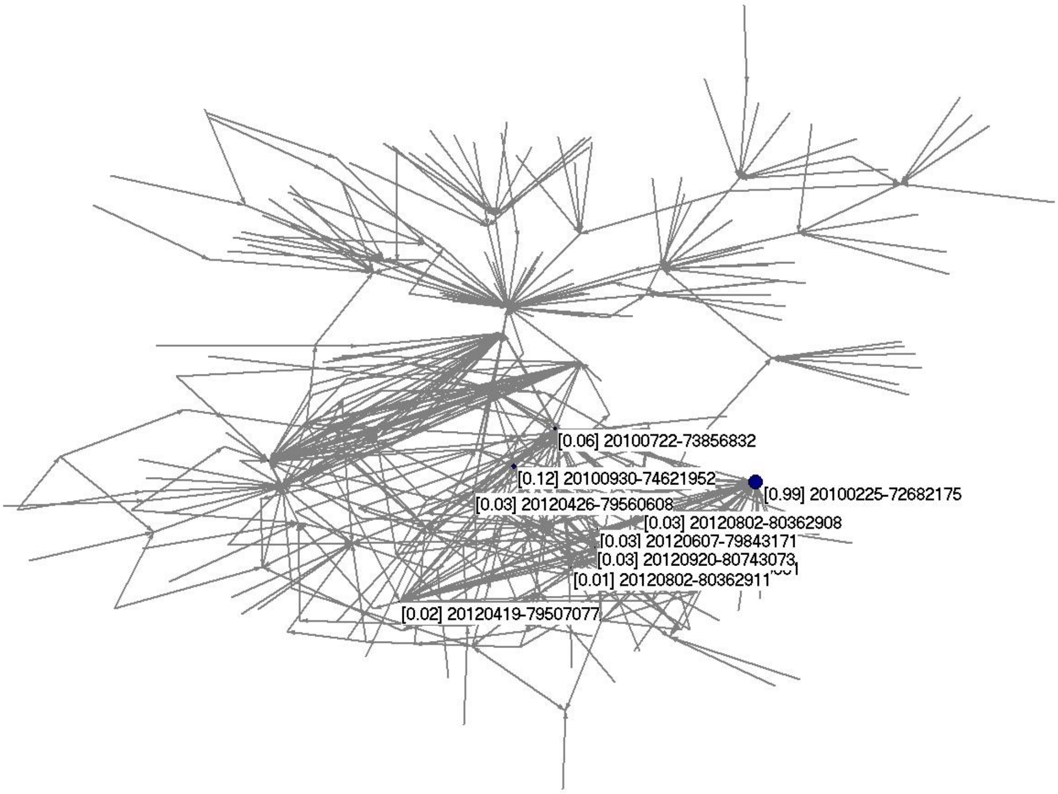

Figure 5.4.NP42. The authority patents of NP42

<u>*Hub weights (Figure 5.4.NP42, Table 5.11.NP42)*</u> – The best developments of the previously identified authority patents are:

- vertex 244, published in the US by the German Solon corporation, with the title 'Solar installation including at least one solar module having spring-loaded mounting of the cover plate';
- vertex 225, published simultaneously in different countries, by seven American inventors, with the title 'Skirt with photovoltaic arrays';
- vertex 187, published in Italy by the Italian company M. System, with the title in original language 'Struttura modulare di sostegno per pannelli fotovoltaici';
- vertex 178, published simultaneously in several different countries by the American company Alion, with the title 'Electrical interconnects for photovoltaic modules and methods thereof';

- vertex 158, published in Europe by the American Solon, with the title 'Supporting plate for holding solar modules on a flat substrate and supporting plate array'.

Table 5.11.NP42. The hub patents of NP42

Rank	Vertex	Value	Id (Label)
1	244	0.42	20120807-74317070
2	225	0.40	20120614-79907276
3	187	0.40	20120311-75409607
4	178	0.40	20120209-79083331
5	158	0.40	20111214-76599314
6	128	0.40	20110922-76208080
7	204	0.11	20120501-75971719
8	242	0.10	20120802-80362911
9	66	0.05	20100930-74621952
10	52	0.04	20100722-73856832

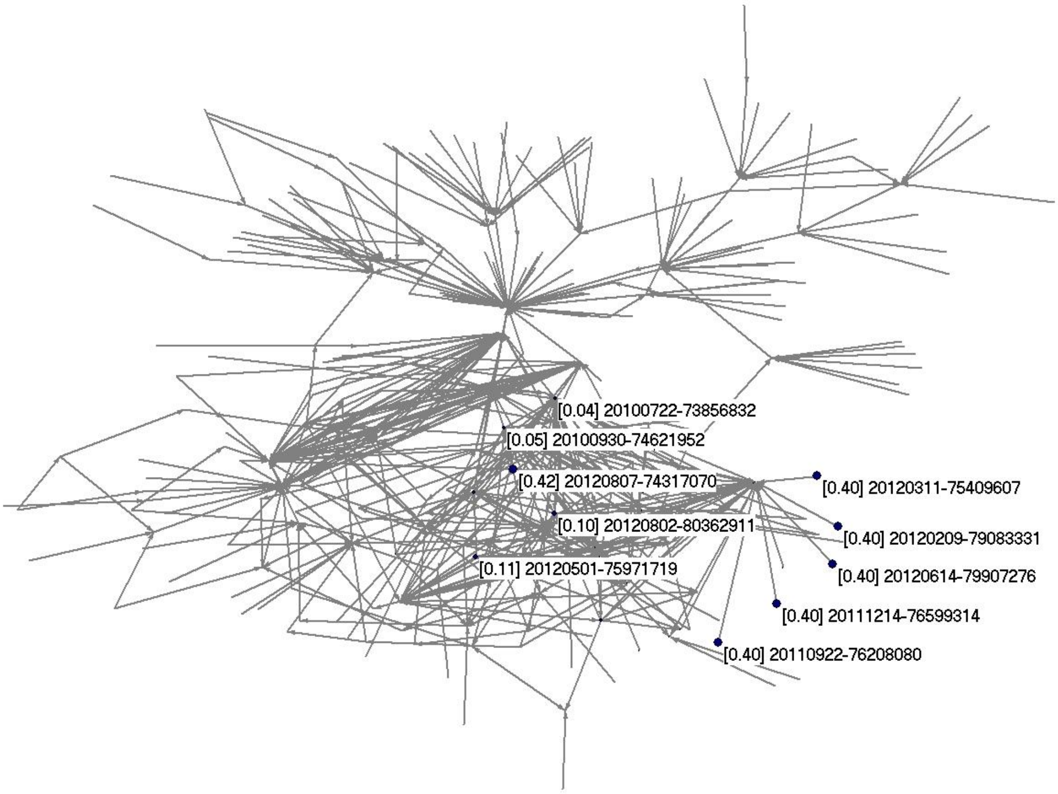

Figure 5.4.NP42. The hub patents of NP42

SPC (Figure 5.6.NP42, Table 5.12.NP42) – The technological trajectory of NP42 comprises 17 patents as shown in Figure 5.6.NP42. This goes from P42 to vertex 294, published in US by a private American inventor, with the title 'Solar panel fixtures and installations'.

Table 5.12.NP42. Vertices on main path SPC [flow] of NP42

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000913-21316396
2	2	1	20050426-59281764
3	12	1	20070220-59281860
4	53	1	20100727-73875633
5	84	1	20110301-75998054
6	181	1	20120228-79192412
7	175	1	20120202-79038083
8	40	1	20100225-72682175
9	82	1	20110203-75814632
10	171	1	20120117-74504865
11	207	1	20120503-79594864
12	244	1	20120807-74317070
13	183	1	20120301-79199318
14	200	1	20120424-75930454
15	203	1	20120426-79561668
16	204	1	20120501-75971719
17	294	1	20130108-81282638

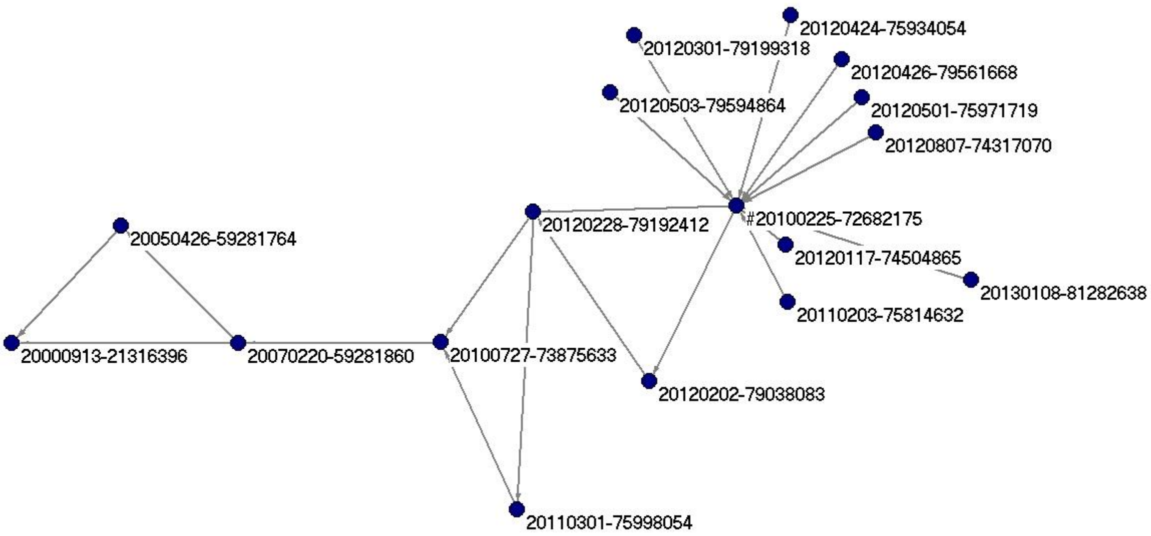

Figure 5.6.NP42. SPC of NP42

Network and connectivity analysis of network built on P43 (NP43)- 20000202-21328563

P43 is a European patent, owned by the American company BP Solarex, with the title 'Photovoltaic module framing system with integral electrical raceways' (IPC: E04D13/18, E04D3/40, H01L31/02). NP43 characteristics are given in Table 5.7.NP43.

Table 5.7.NP43. Characteristics

Number of vertices (n)	**362**
	Arcs
Total number of lines	532
Number of loops	2
Number of multiple lines	0
Density [loops allowed]	0.00
Average degree	2.93

In-degree centrality (Figure 5.1.NP43, Table 5.8.NP43) – The most cited patent along NP43 is vertex 9, owned by the First Solar company, with the title 'Photovoltaic panel mounting bracket' (IPC: E06B1/04).

Table 5.8.NP43. Top 10 in-degree and out-degree centrality values of NP43

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	9	58	20051101-63652078	48	25	20100225-72682175
2	19	35	20080805-67067215	64	20	20100722-73856832
3	39	23	20091013-66608669	81	16	20101026-72030361
4	48	21	20100225-72682175	75	16	20100930-74621952
5	10	21	20060824-01695682	191	14	20111103-78041250
6	1 (P43)	18	20000202-21328563	79	12	20101021-74905460
7	15	16	20071211-65573169	261	12	20120501-75971719
8	237	14	20120306-75164025	300	11	20120802-80362911
9	162	14	20110802-67086912	242	10	20120329-79403836
10	17	14	20080723-00019205	213	10	20111229-78745696

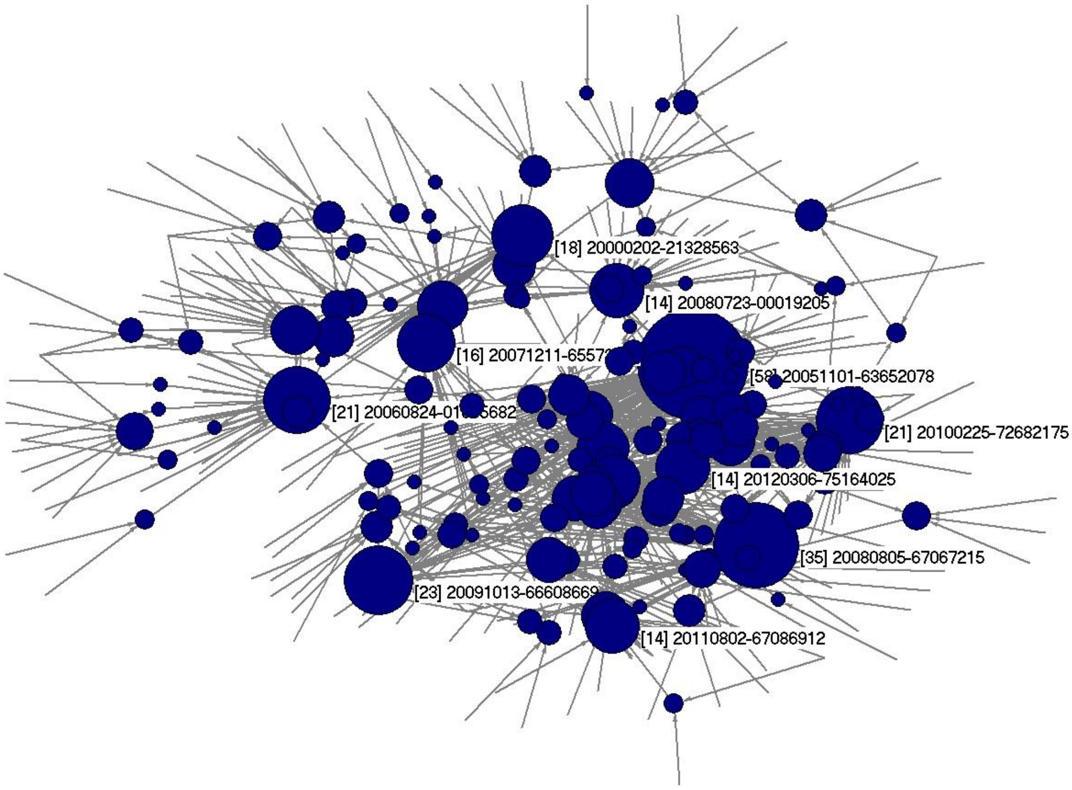

Figure 5.1.NP43. In-degree centrality of NP43

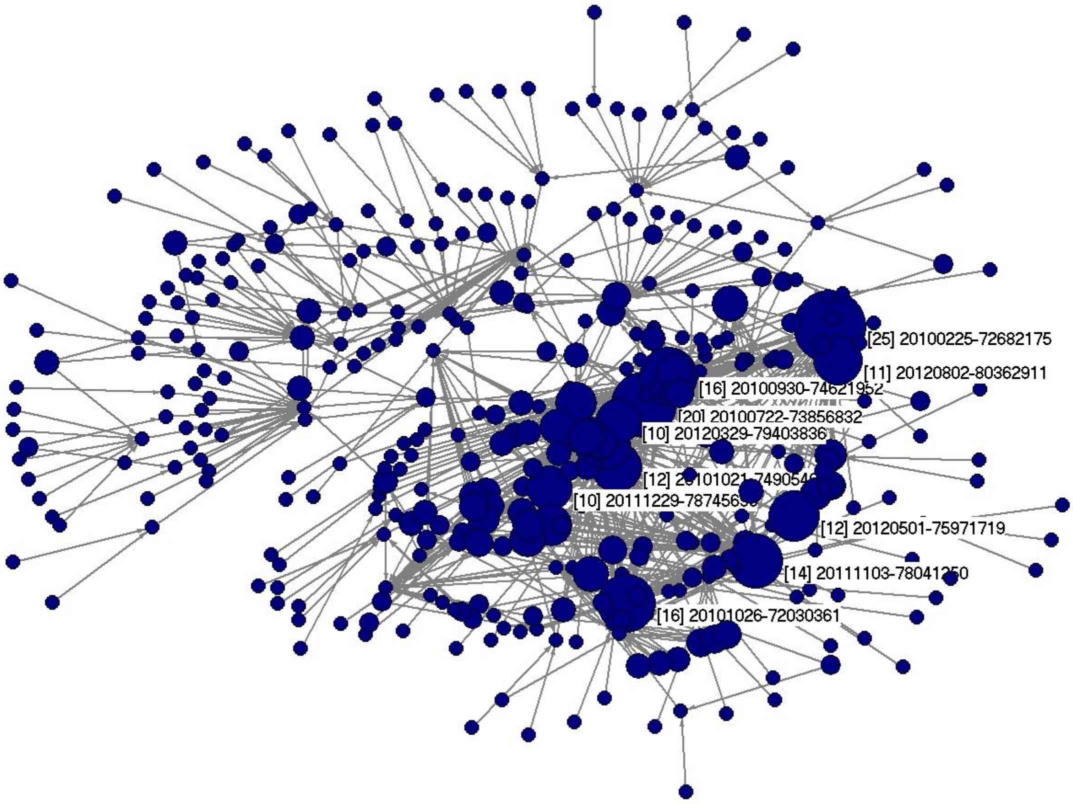

Figure 5.2.NP43. Out-degree centrality of NP43

<u>Closeness centrality (Figure 5.3.NP43, Table 5.9.NP43)</u> – P43 is ranked 2nd among the top 10 patents according to the closeness centrality measure. The 1st ranked is vertex 9 which is also the most cited along NP43. The patents ranked 3rd to 7th have the same closeness centrality value (0.33). The 3rd ranked patent (vertex 64), is owned by the American CertainTeed Corporation, with the title 'Photovoltaic roof covering'.

Table 5.9.NP43. Closeness centrality values of NP43

Rank	Vertex	Value	Id (Label)
1	9	0.38	20051101-63652078
2	1 (P43)	0.35	20000202-21328563
3	64	0.33	20100722-73856832
4	170	0.33	20110901-77465610
5	39	0.32	20091013-66608669
6	48	0.32	20100225-72682175
7	19	0.32	20080805-67067215
8	75	0.31	20100930-74621952
9	79	0.31	20101021-74905460
10	28	0.31	20090506-69650748

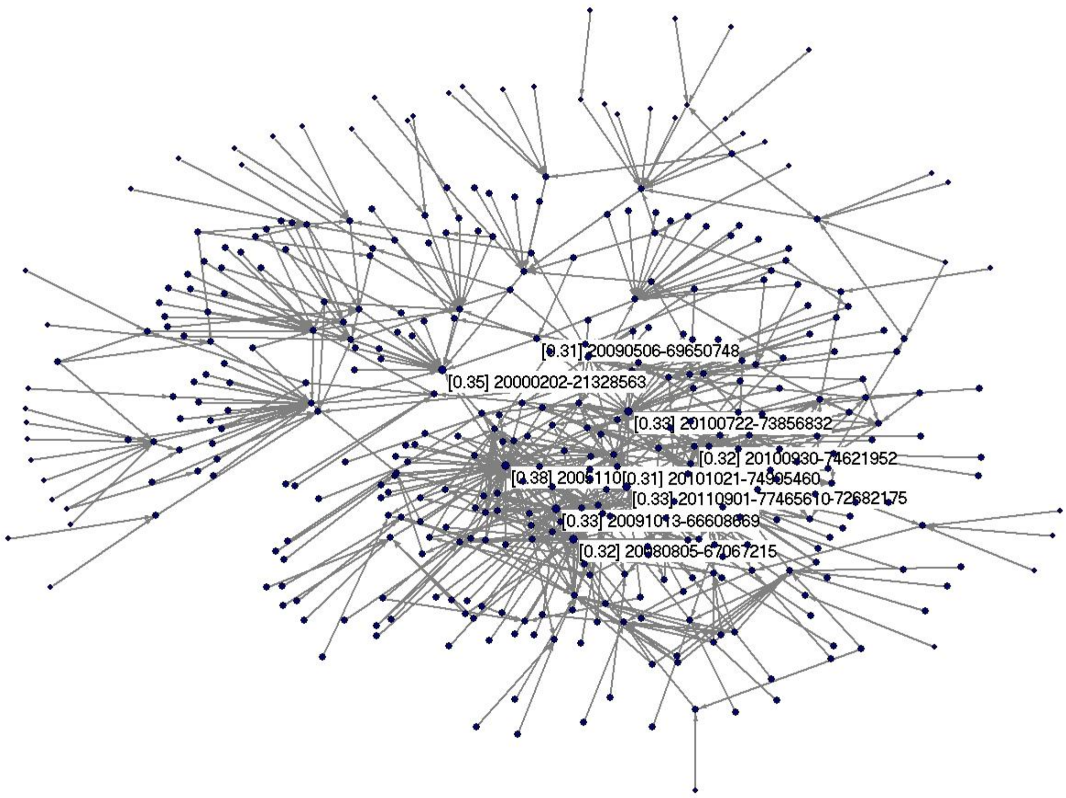

Figure 5.3.NP43 closeness centrality of NP43

Authority weights (Figure 5.4.NP43, Table 5.10.NP43) – The highest authority patents of NP43 are given in Table 5.10.NP43 and depicted in the Figure 5.4.NP43. The most authority is vertex 48, published by the American company SoCore Energy, with the title 'Solar panel support module and method for creating array of interchangeable and substitutable solar panel support modules'. There are four other authorities with smaller values (0.03, 0.02 and 0.01). They are:

- vertex 75, published in the US by a private inventor Jenkins Robert with the title 'Photovoltaic systems, method for installing photovoltaic systems and kits for installing';
- vertex 81, published in the US by Solar Red Systems, with the title 'Plug and play solar panel assembly';
- vertex 327, published in the US by a private inventor, with the title 'Unitized photovoltaic assembly';
- vertex 252, published in the US by the American company Solar Power Products Corporation, with the title 'Support for solar panel'.

Table 5.10.NP43. The authority patents of NP43

Rank	Vertex	Value	Id (Label)
1	48	1	20100225-72682175
2	75	0.03	20100930-74621952
3	81	0.03	20101026-72030361
4	327	0.02	20120920-80743073
5	252	0.01	20120419-79507077

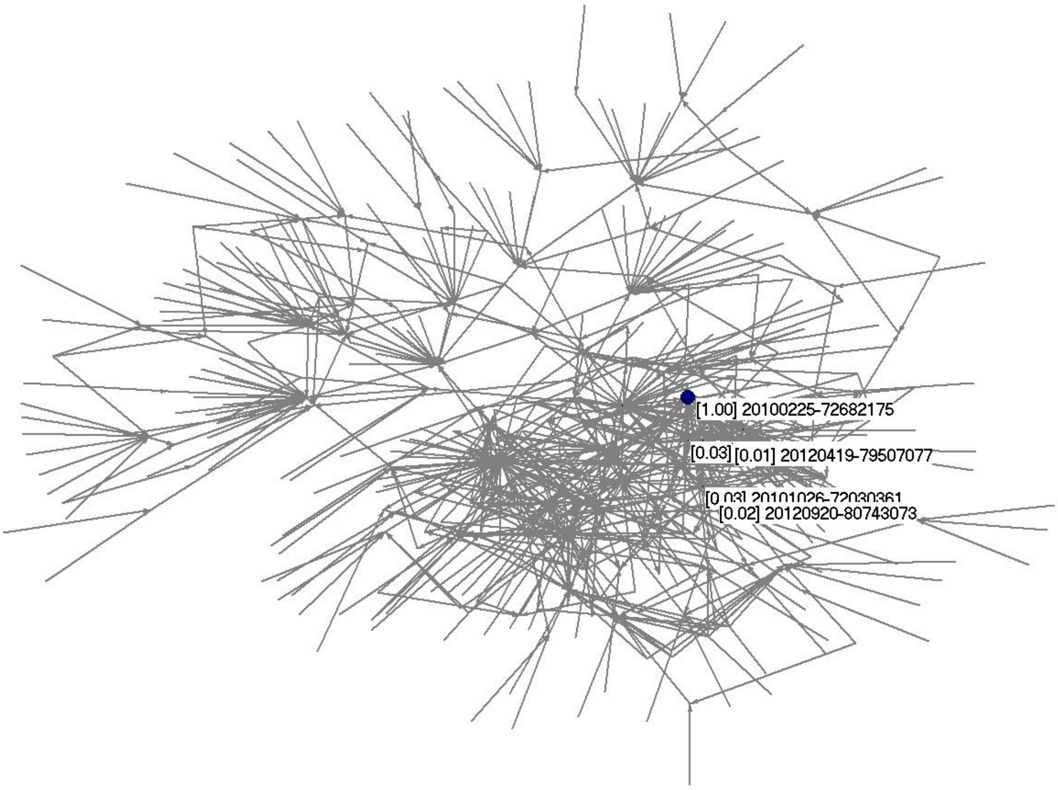

Figure 5.4.NP43. The authority patents of NP43

<u>*Hub weights (Figure 5.4.NP43, Table 5.11.NP43)*</u> – The top five patents are:

- vertex 303, published in the US by the German company Solon, entitled 'Solar installation including at least one solar module having a spring-loaded mounting of the cover plate';
- vertex 238, published in Italy, by the Italian company System SNMC, entitled 'Struttura modulare di sostegno per pannelli fotovoltaici';
- vertex 232, published simultaneously in several different countries, by the American company Alion Inc., entitled 'Electrical interconnects for photovoltaic modules and methods thereof';
- vertex 207, published in Europe by the German company Solon, entitled 'Supporting plate for holding solar modules on a flat substrate and supporting plate array';

- vertex 172, published simultaneously in several different countries, by the German Poppelmann Holding GmbH & Co., entitled 'Solar module supporting module, solar module supporting structure and solar installation'.

Table 5.11.NP43. The hub patents of NP43

Rank	Vertex	Value	Id (Label)
1	303	0.41	20120807-74317070
2	238	0.40	20120311-75409607
3	232	0.40	20120209-79083331
4	207	0.40	20111214-76599314
5	172	0.40	20110922-76208080
6	286	0.40	20120614-79907276
7	191	0.12	20111103-78041250
8	300	0.03	20120802-80362911
9	261	0.03	20120501-75971719
10	81	0.02	20101026-72030361

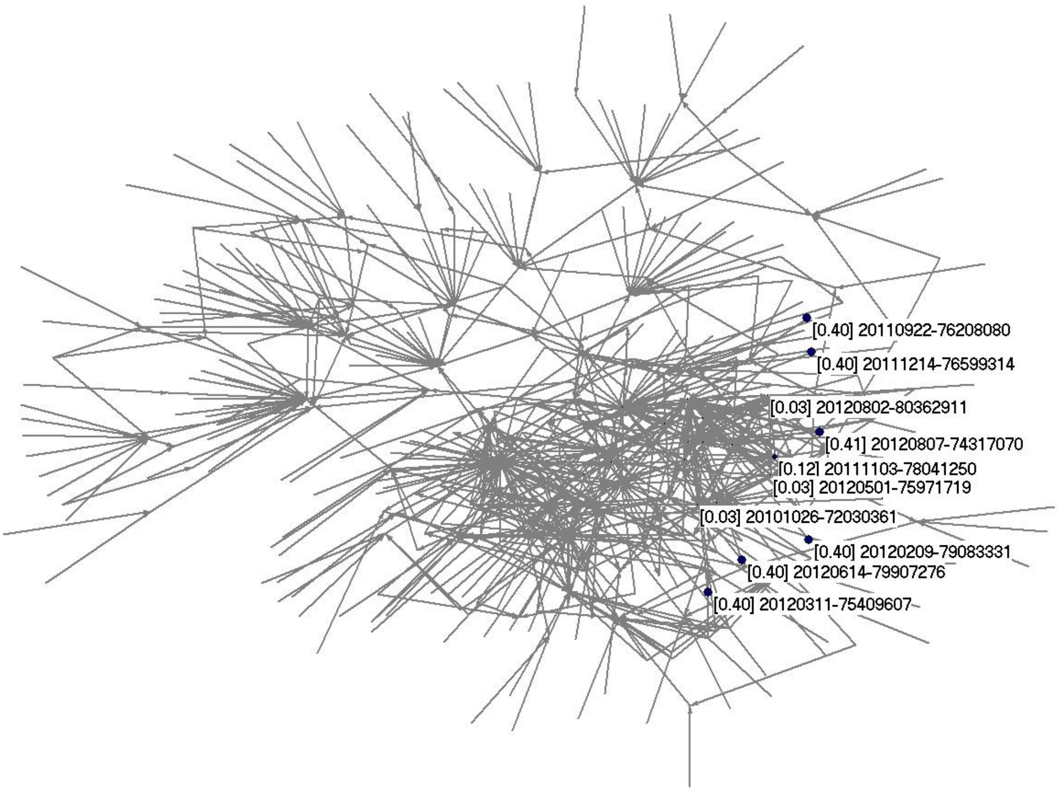

Figure 5.4.NP43. The hub patents of NP43

SPC (Figure 5.6.NP43, Table 5.12.NP43) – The technological trajectory depicted in Figure 5.6.NP43 comprises 20 patents. P43 represents a focal point from which a more complex network propagates. Another focal point is patent vertex 35, published in the US by the American CertainTeed Corporation, with the title 'Roofing and siding products having receptor zones and photovoltaic roofing and siding elements and systems using them'.

Table 5.12.NP43. Vertices on main path SPC [flow] of NP43

Rank	Cluster	Id (Label)
1	1	20000202-21328563
2	35	20090716-70900482
3	28	20090506-69650748
4	261	20120501-75971719
5	126	20110324-76202018
6	257	20120426-79561668
7	11	20070426-21505009
8	236	20120301-79199318
9	231	20120209-79073234
10	9	20051101-63652078
11	190	20111103-78038101
12	19	20080805-67067215
13	178	20111006-77709294
14	17	20080723-00019205
15	84	20101116-65229847
16	72	20100921-58068604
17	303	20120807-74317070
18	281	20120605-78451758
19	385	20130108-77275749
20	306	20130108-81282638

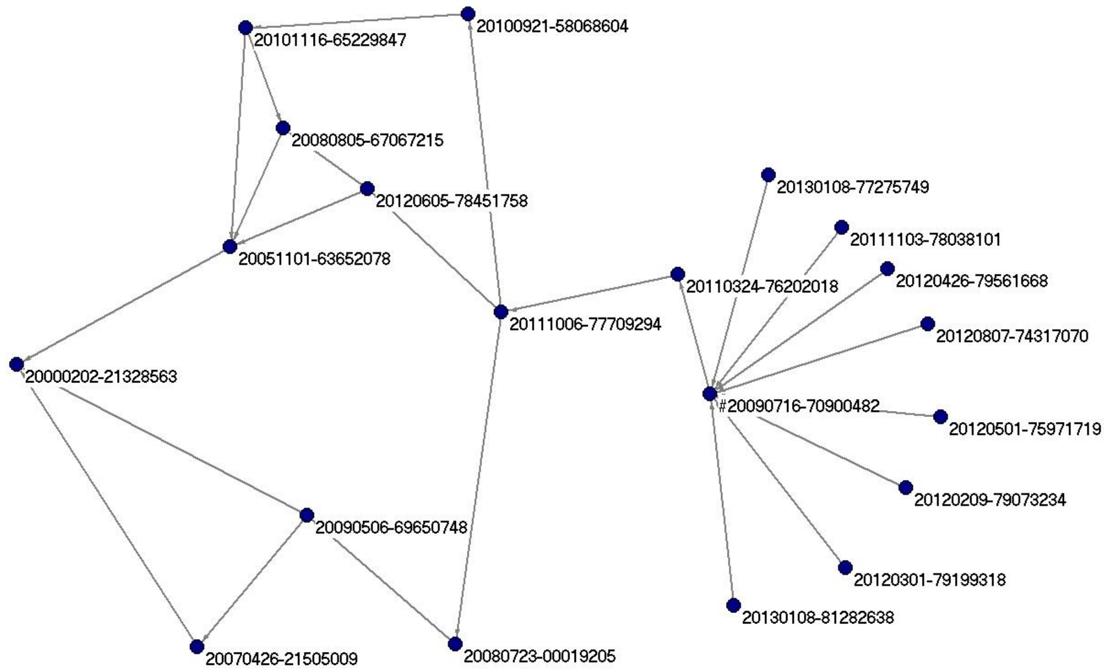

Figure 5.6.NP43. SPC of NP43

Network and connectivity analysis of network built on P44 (NP44)- 20000308-21331092

P44 is a European patent published by the British company English Electric Valve, entitled 'Solar cell with a protection diode' (IPC: H01L27/142). NP44 characteristics are given in Table 5.7.NP44.

Table 5.7.NP44. Characteristics

Number of vertices (n)	**19**
	Arcs
Total number of lines	21
Number of loops	0
Number of multiple lines	2
Density [loops allowed]	0.05
Average degree	2.21

In-degree centrality (Figure 5.1.NP44, Table 5.8.NP44) – P44 is the second most cited patent in NP44, with three citations. The most cited patent is vertex 7, published in the US by a private inventor with the title 'Portable survival kit'.

Table 5.8.NP44. In-degree and out-degree centrality values of NP44

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	7	6	20090728-66063768	10	2	20110505-76504285
2	1 (P44)	3	20000308-21331092	19	1	20121211-69777641
3	2	3	20010103-21337825	18	1	20120703-76504268
4	4	2	20030826-61173902	17	1	20120621-79218212
5	8	2	20110208-69736743	16	1	20120616-76179023
6	3	1	20020711-31971168	15	1	20120410-70765107
7	6	1	20090226-69976362	14	1	20120403-69710712
8	5	1	20040206-23543727	13	1	20120329-79405190
9				12	1	20110810-72533102
10				3	1	20020711-31971168

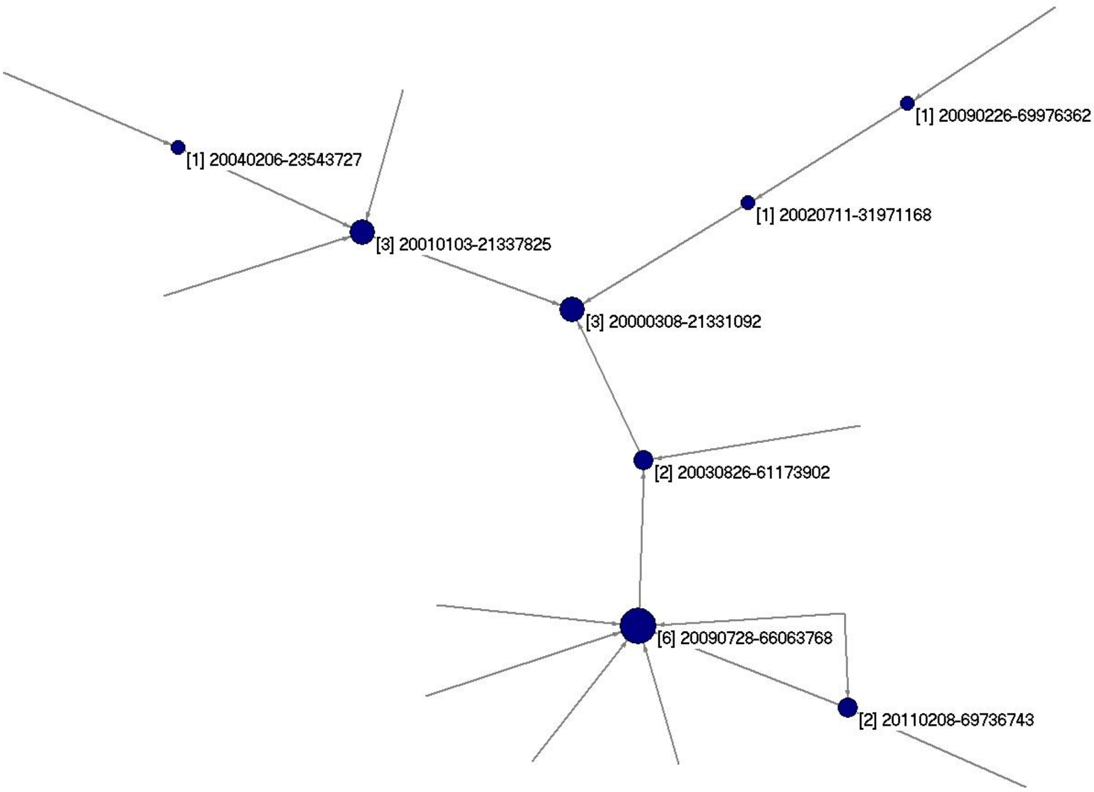

Figure 5.1.NP44. In-degree centrality of NP44

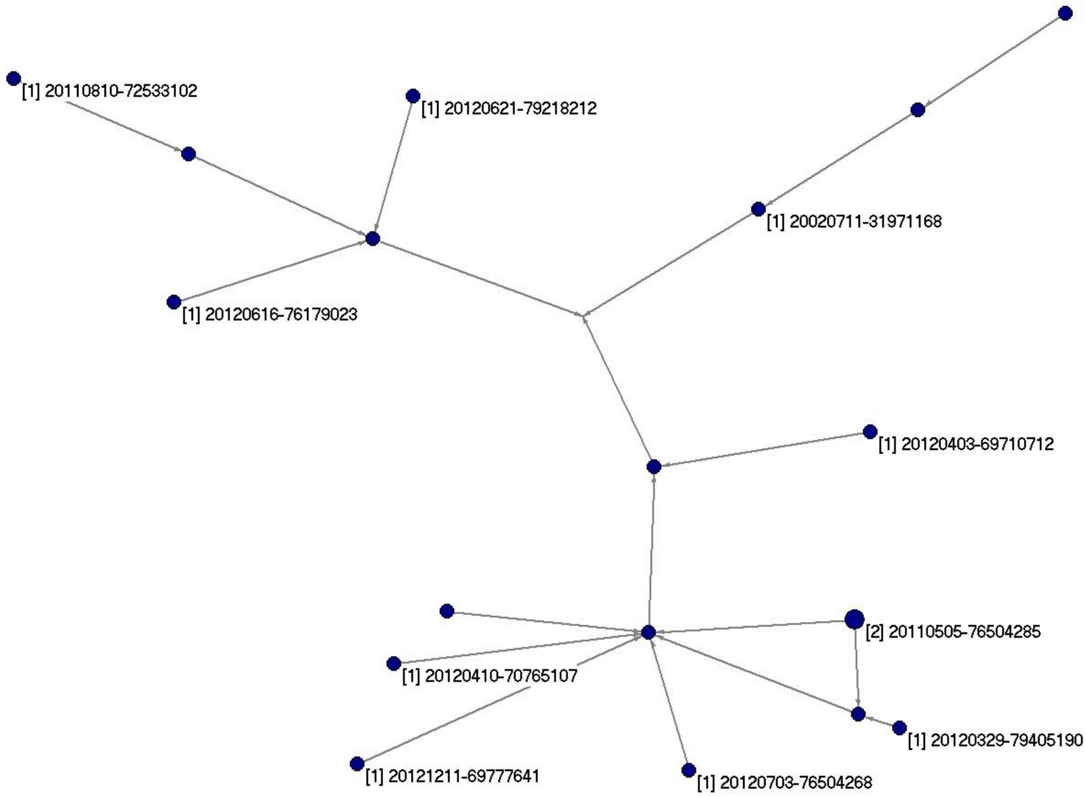

Figure 5.2.NP44. Out-degree centrality of NP44

Closeness centrality (Figure 5.3.NP44, Table 5.9.NP44) – According to the closeness centrality measure, vertex 4 is ranked 1st among the top 10. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Fig. 6.3.NP44, which shows vertex 4 lying at the centre of the surrounding clusters. P44 occupies the second position.

Table 5.9.NP44. Closeness centrality values of NP44

Rank	Vertex	Value	Id (Label)
1	4	0.43	20030826-61173902
2	1 (P44)	0.42	20000308-21331092
3	7	0.40	20090728-66063768
4	2	0.35	20010103-21337825
5	3	0.32	20020711-31971168
6	14	0.30	20120403-69710712
7	8	0.30	20110208-69736743
8	10	0.30	20110505-76504285
9	15	0.29	20120410-70765107

10	18	0.29	20120703-76504268

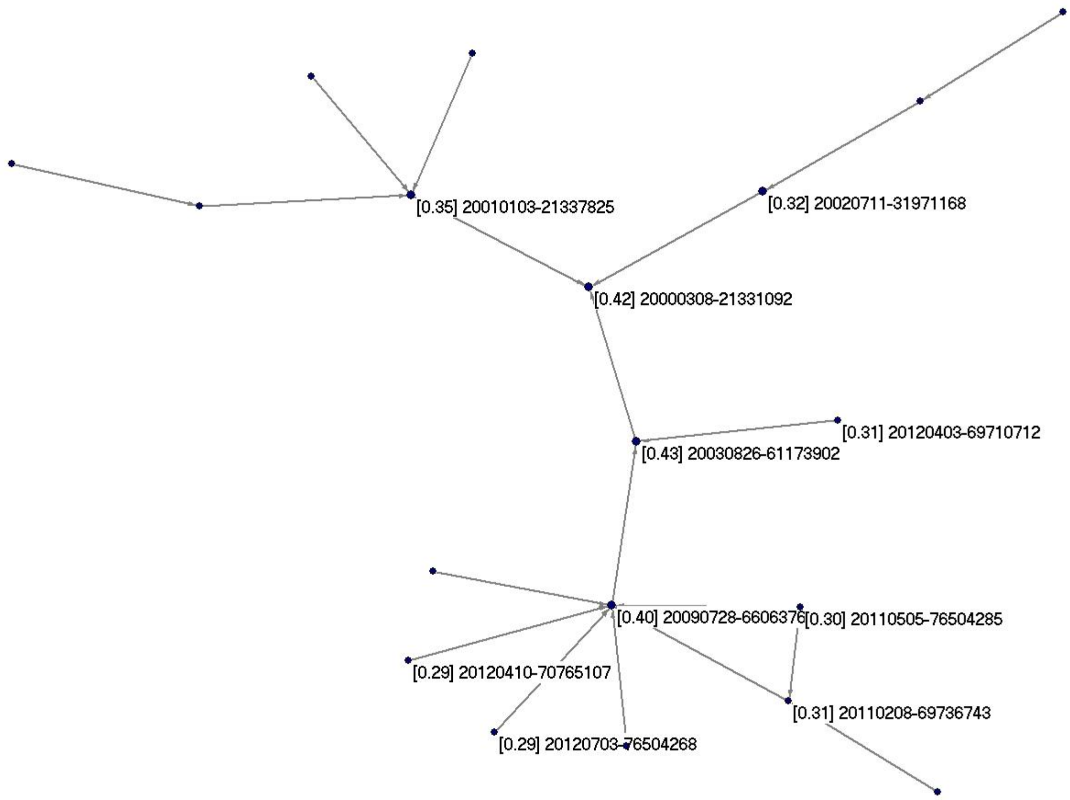

Figure 5.3.NP44. Closeness centrality of NP44

Authority weights (Figure 5.4.NP44, Table 5.10.NP44) – The two authorities in NP44 are:

- vertex 7, already mentioned as the most cited patent in NP44;
- vertex 8, published in the US by the American company Zerobase Energy LLC, entitled 'Deployable power supply system'.

Table 5.10.NP44. The authority patents of NP44

Rank	Vertex	Value	Id (Label)
1	7	0.97	20090728-66063768
2	8	0.24	20110208-69736743

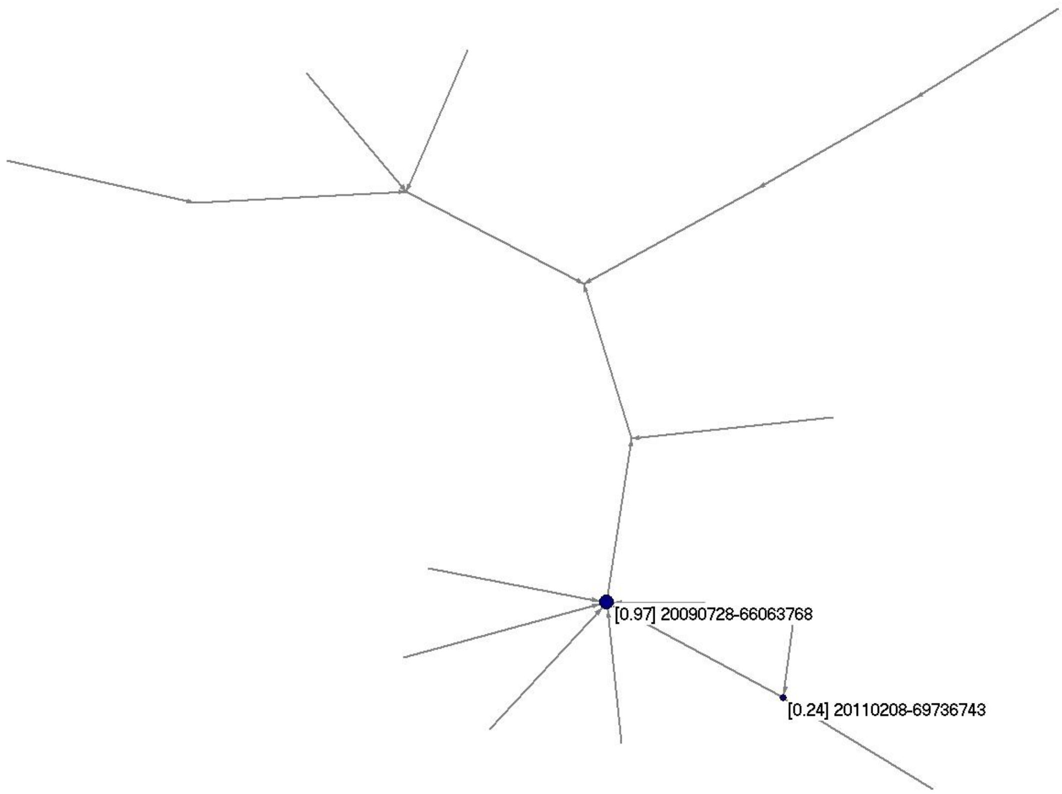

Figure 5.4.NP44. The authority patents of NP44

<u>*Hub weights (Figure 5.4.NP44, Table 5.11.NP44)*</u> – There are seven hub patents in NP44:

- vertex 18, published in the US by the American company Zerobase Energy LLC, entitled 'Deployable power supply system'. It is a second version, published one year later, of the second authority patent in NP44;
- vertex 10, published in the US by a private inventor, entitled 'Portable power supply device';
- vertex 15, published in the US by the American company Intec Inc., entitled 'Portable hand held multi-source power inverter with pass through device';
- vertex 11, published in the US by the American Audiovox Corporation, entitled 'Method and apparatus for harvesting energy';
- vertex 19, published in the US by the German company Solarworld, entitled 'Charger for minimal – power consumers'.

Table 5.11.NP44. The hub patents of NP44

Rank	Vertex	Value	Id (Label)
1	18	0.64	20120703-76504268
2	10	0.40	20110505-76504285
3	15	0.32	20120410-70765107
4	11	0.32	20110721-77103705
5	19	0.32	20121211-69777641
6	8	0.32	20110208-69736743
7	13	0.16	20120329-79405190

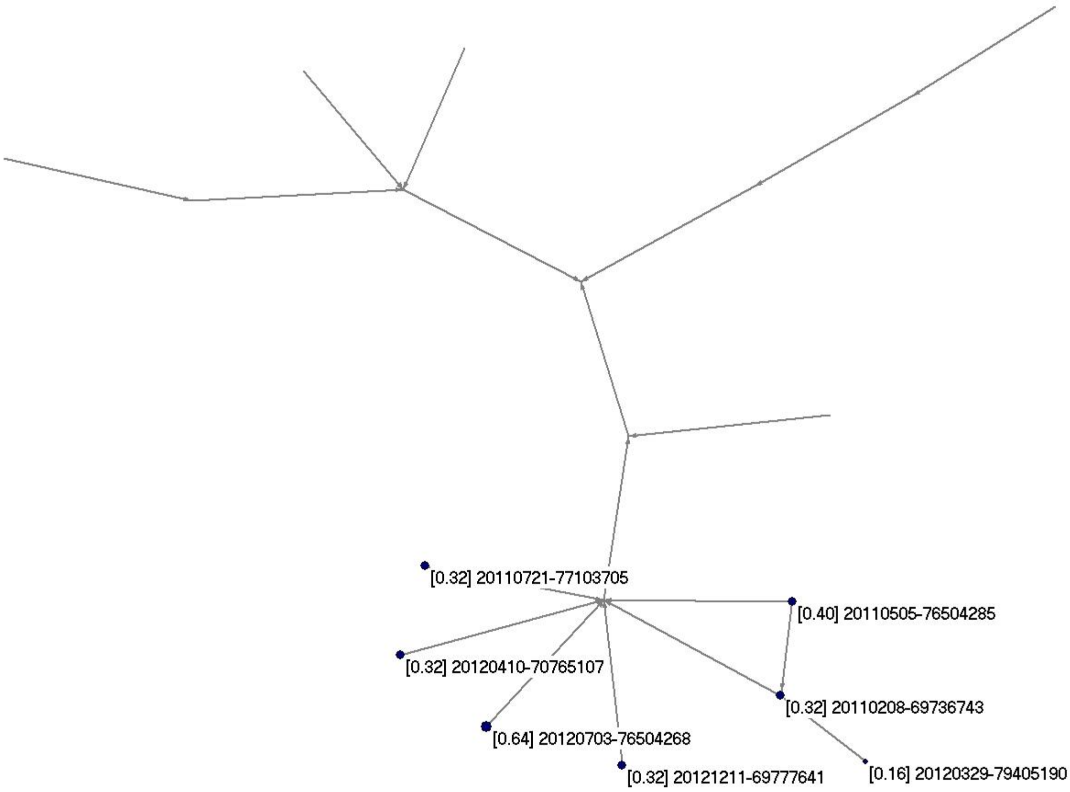

Figure 5.4.NP44. The hub patents of NP44

<u>*SPC (Figure 5.6.NP44, Table 5.12.NP44)*</u> – Figure 5.6.NP44 depicts the technological trajectory of NP4, which comprises all 19 patent in NP44. There are two focal points emerge, from which many other patents emerge with P44 and vertex 7, which has been described as the most cited and the first authority in NP44.

Table 5.12.NP44. Vertices on main path SPC [flow] of NP44

Rank	Vertex	Cluster	Id (Label)

1	1	1	20000308-21331092
2	2	1	20010103-21337825
3	3	1	20020711-31971168
4	4	1	20030826-61173902
5	5	1	20040206-23543727
6	6	1	20090226-69976362
7	7	1	20090728-66063768
8	8	1	20110208-69736743
9	9	1	20110310-76063329
10	10	1	20110505-76504285
11	11	1	20110721-77103705
12	12	1	20110810-72533102
13	13	1	20120329-79405190
14	14	1	20120403-69710712
15	15	1	20120410-70765107
16	16	1	20120616-76179023
17	17	1	20120621-79218212
18	18	1	20120703-76504268
19	19	1	20121211-69777641

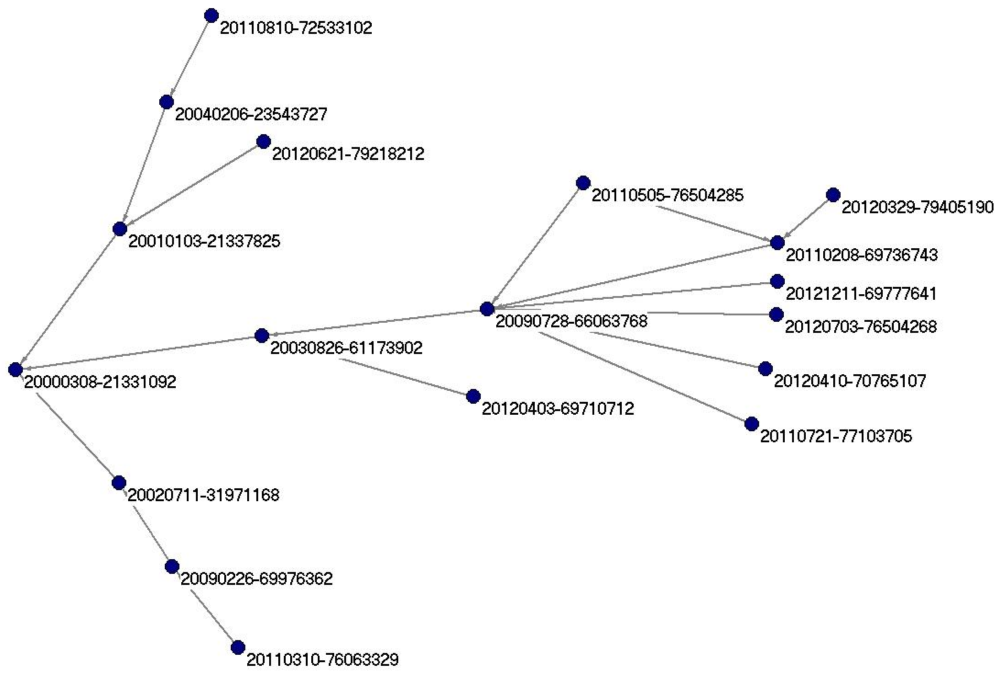

Figure 5.6.NP44. SPC of NP44

Network and connectivity analysis of network built on P45 (NP45) - 20000510-21333832

P45 is a European patent owned by the Japanese company Sumitomo Wiring Systems, with the title 'A terminal box device, and a solar panel and terminal box device assembly' (IPC: H01L31/02). NP45 characteristics are given in Table 5.7.NP45.

Table 5.7.NP45. Characteristics

Number of vertices (n)	**349**
	Arcs
Total number of lines	788
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.00
Average degree	4.51

<u>*In-degree centrality (Figure 5.1.NP45, Table 5.8.NP45)*</u> - According to the in-degree centrality values, P45 is the most cited patent in NP45, with 34 citations. The next most cited is vertex 3, owned by the German Tyco Electronics AMP GmbH, with the title in the original language 'Anschlussdose für ein Solarpaneel und Solarpaneel'.

Table 5.8.NP45. Top 10 in-degree and out-degree centrality values of NP45

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	1 (P45)	34	20000510-21333832	328	39	20121113-78039768
2	3	29	20040708-15789814	126	20	20100722-73856832
3	10	29	20060829-67365978	252	17	20120329-79407826
4	2	23	20040219-15789815	291	16	20120626-76379281
5	5	23	20050825-17082243	132	16	20100930-74621952
6	13	21	20061206-19090049	246	14	20120301-79199318
7	252	18	20120329-79407826	187	12	20110616-76868845
8	20	18	20071025-21524608	155	12	20110106-75606264
9	31	15	20080617-65252026	231	11	20120117-58857259
10	11	15	20061114-67365259	306	11	20120802-80362911

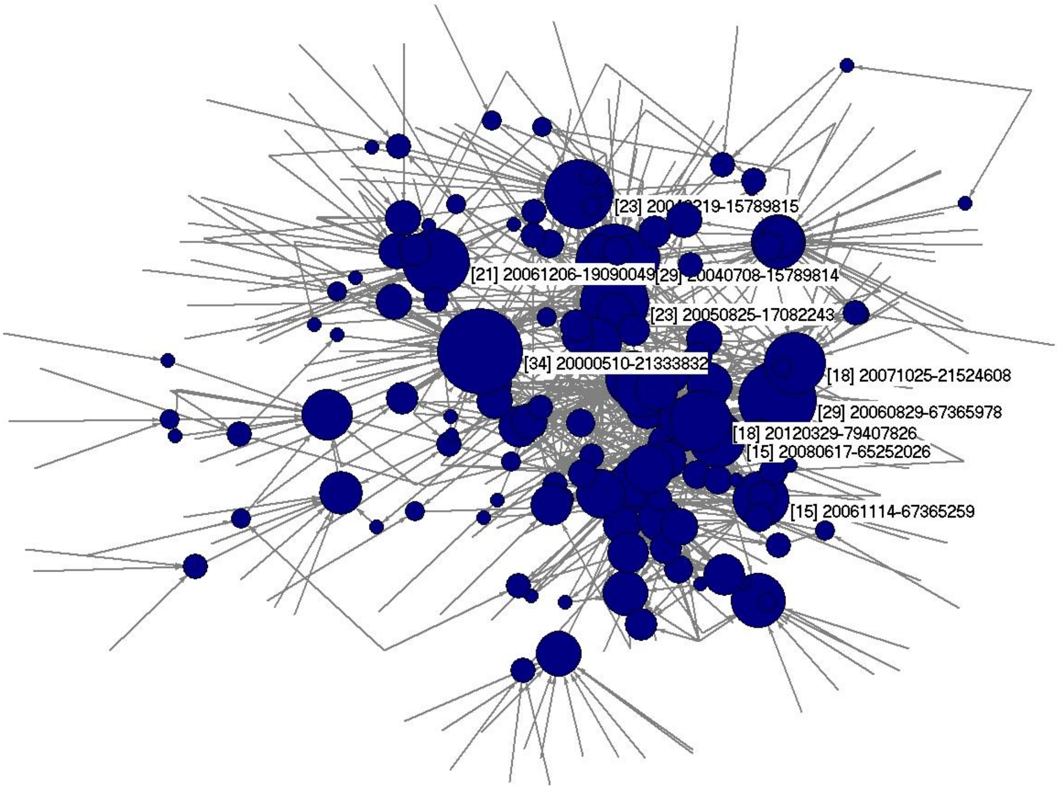

Figure 5.1.NP45. In-degree centrality of NP45

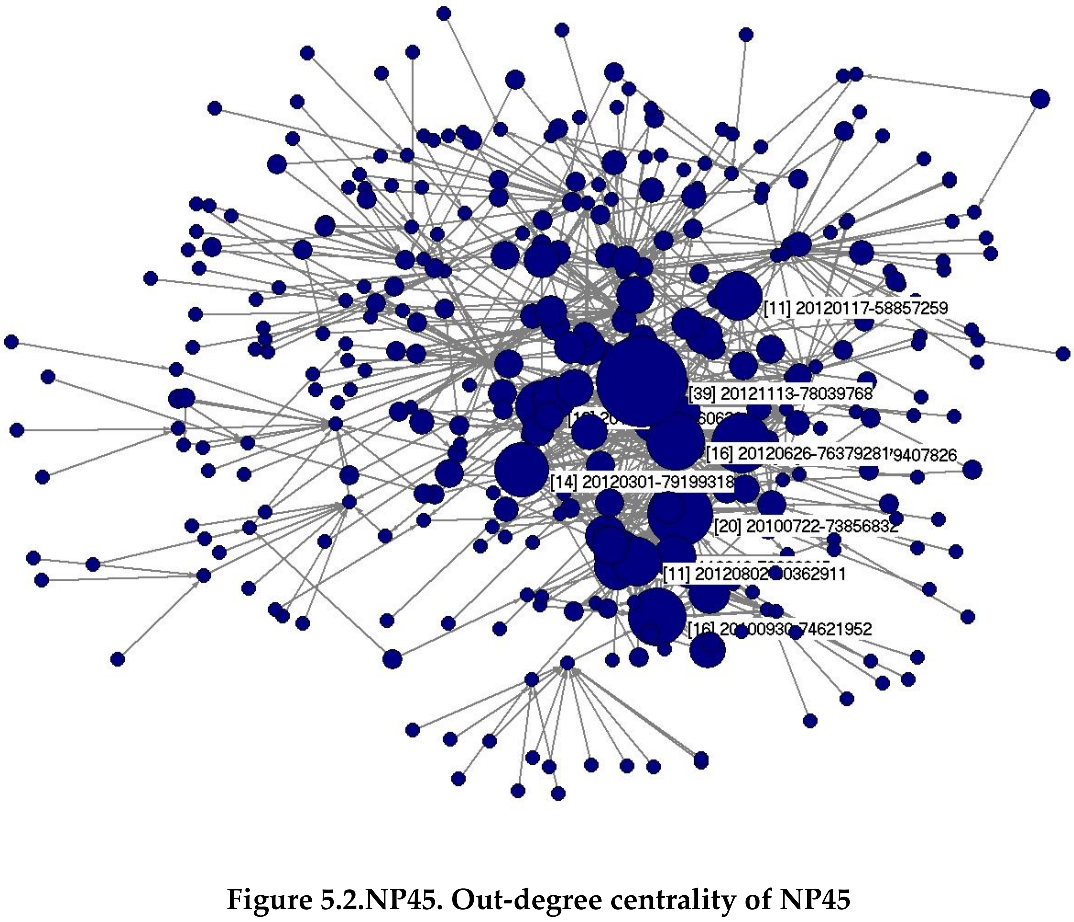

Figure 5.2.NP45. Out-degree centrality of NP45

Closeness centrality (Figure 5.3.NP45, Table 5.9.NP45) – Measured by closeness centrality, P45 is also the closest to the centre, followed by vertex 139 published 10 years later, owned by the German company Weidmueller Interface, with the title 'Electrical connector arrangement for flat conductors'.

Table 5.9.NP45. Closeness centrality values of NP45

Rank	**Vertex**	**Value**	**Id (Label)**
1	1 (P45)	0.40	20000510-21333832
2	139	0.38	20101102-73155016
3	252	0.38	20120329-79407826
4	328	0.38	20121113-78039768
5	3	0.37	20040708-15789814
6	10	0.36	20060829-67365978
7	247	0.36	20120306-77243626
8	90	0.36	20100119-00673757
9	126	0.36	20100722-73856832
10	219	0.35	20111213-74322065

Figure 5.3.NP45. Closeness centrality of NP45

<u>*Authority weights (Figure 5.4.NP45, Table 5.10.NP45)*</u> – P45 is not an authority patent in NP45. The top five are:

- vertex 187, owned by the Samsung Corporation, with the title 'Power converting device for new renewable energy storage system';
- vertex 291, owned by five private inventors, with the title 'System and apparatus for interconnecting an array of power generating assembles'.
- vertex 232, owned by the Finnish ABB Group, with the title 'Method and arrangement in wind power plant';
- vertex 202, owned by the American Hamilton Sundstrand Corporation, with the title 'Multi-level parallel phase converter';
- vertex 126, owned by the American CertainTeed Corporation, with the title 'Photovoltaic roof covering'.

Table 5.10.NP45. The authority patents of NP45

Rank	**Vertex**	**Value**	**Id (Label)**
1	187	0.96	20110616-76868845
2	291	0.26	20120626-76379281
3	232	0.04	20120117-67868918
4	202	0.04	20110929-77632730
5	126	0.03	20100722-73856832
6	95	0.03	20100225-72682175
7	137	0.03	20101026-72030361
8	316	0.02	20120920-80743073
9	163	0.02	20110308-74930119
10	252	0.02	20120329-79407826

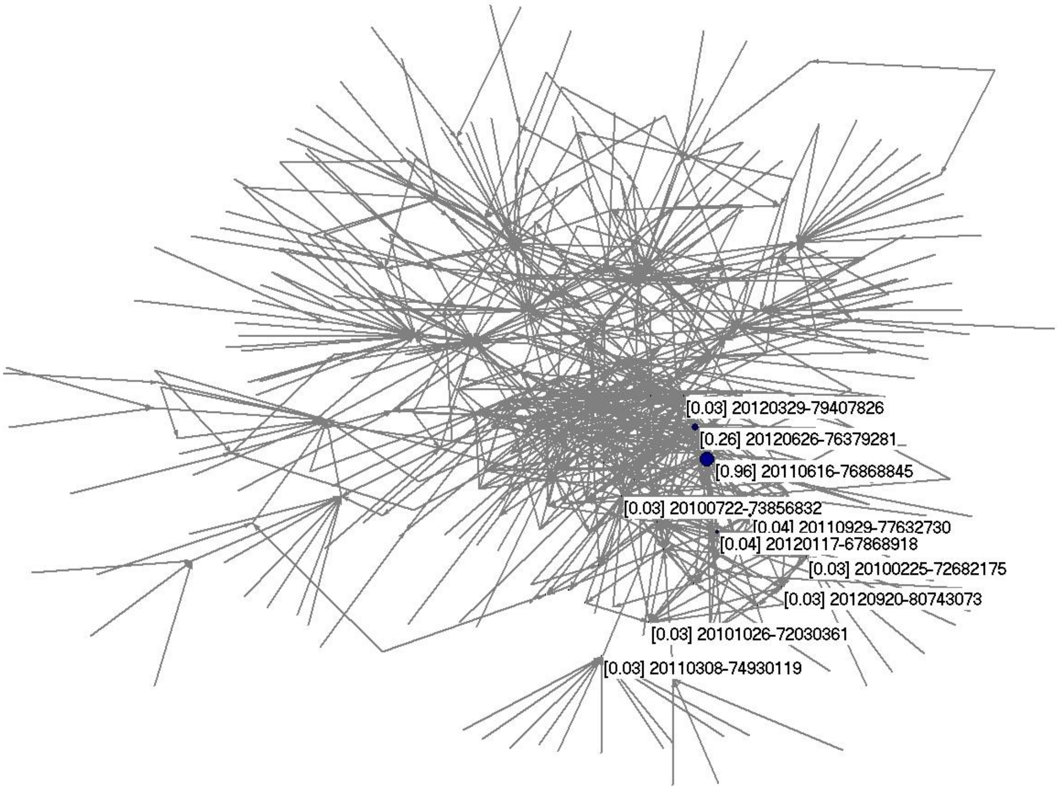

Figure 5.4.NP45. The authority patents of NP45

Hub weights (Figure 5.4.NP45, Table 5.11.NP45) – The first five best developments are:

- vertex 324, published in Germany by the German Siemens Corporation, with the title in the original language, 'Energiespeichervorrichtung, umfassend mehrere Speichermodule für elektrische Energie';
- vertex 296, published in the US by the German company Solar Technology, with the title 'Bidirectional inverter for conversion between a direct current source and an alternating current grid';
- vertex 119, published in the US by the American company Enphase Energy, with the title 'Mounting rail and power distribution system for use in a photovoltaic system';
- vertex 225, published in the US by a private inventor with the title ' Solar energy collection systems and method';

- vertex 210, published in the US by the American General Electric, with the title 'System and method for protection of a multilevel converter'.

Table 5.11.NP45. The hub patents of NP45

Rank	Vertex	Value	Id (Label)
1	324	0.62	20121031-80990903
2	296	0.62	20120710-78814954
3	119	0.40	20100610-73586223
4	225	0.17	20111222-78711342
5	210	0.14	20111103-78038101
6	202	0.11	20110929-77632730
7	306	0.06	20120802-80362911
8	268	0.04	20120501-75971719
9	132	0.04	20100930-74621952
10	211	0.03	20111103-78041250

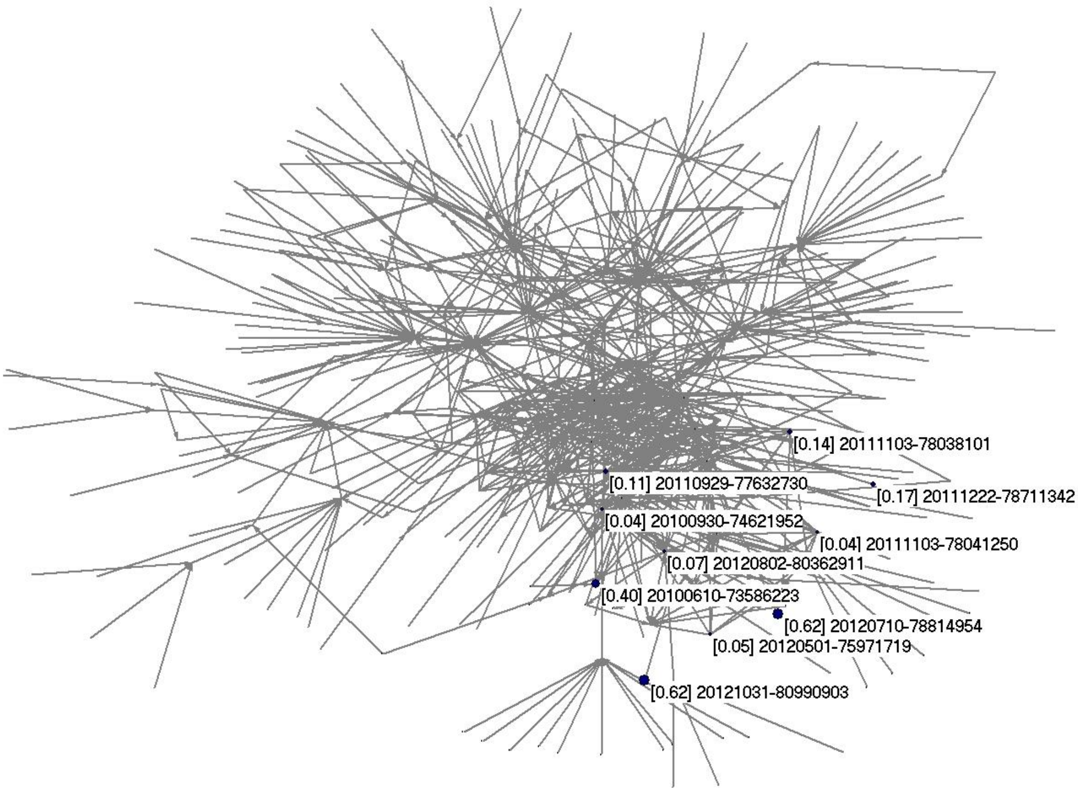

Figure 5.4.NP45. The hub patents of NP45

<u>*SPC (Figure 5.6.NP45, Table 5.12.NP45)*</u> – The SPC algorithm provides a technological trajectory comprising 27 patents. This goes from P45 to the most recent vertex 348, owned

by the American Solarbridge Technologies with the title 'Modular system for unattended energy generation and storage'. Note that one patent represents a focal point, as shown in Figure 5.6.NP45. This is the American patent vertex 72, owned by a private inventor with the title 'Photovoltaic Roofing Elements, Laminates, Systems and Kits'.

Table 5.12.NP45. Vertices on main path SPC [flow] of NP45

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000510-21333382
2	2	1	20040219-15789815
3	3	1	20040708-15789814
4	10	1	20060829-67365978
5	9	1	20060720-07097292
6	85	1	20091215-70535989
7	159	1	20110201-73778022
8	78	1	20091117-71146995
9	131	1	20100902-74387668
10	265	1	20120424-79327262
11	280	1	20120524-79706489
12	268	1	20120501-75971719
13	328	1	20121113-78039768
14	72	1	20091001-71484833
15	210	1	20111103-78038101
16	155	1	20110106-75606264
17	171	1	20110426-73390846
18	125	1	20100715-73623485
19	281	1	20120529-77502789
20	335	1	20121206-79541918
21	307	1	20120807-74317070
22	246	1	20120301-79199318
23	223	1	20111215-78313614
24	271	1	20120503-77906009
25	276	1	20120517-79673857
26	241	1	20120214-78123950
27	348	1	20130108-77275749

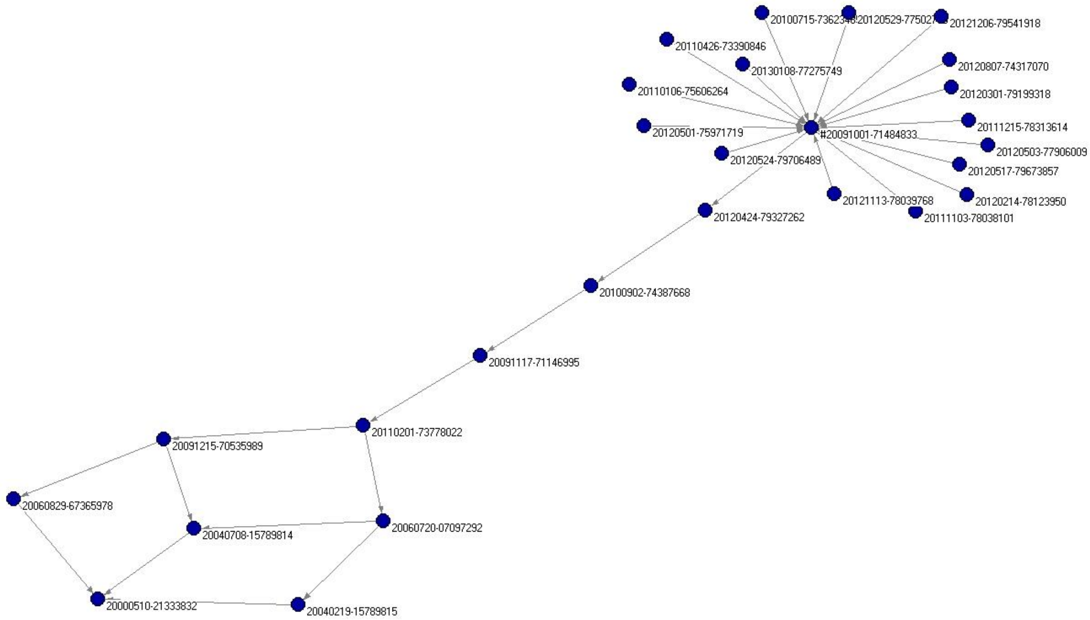

Figure 5.6.NP45. SPC of NP45

Network and connectivity analysis of network built on P46 (NP46) - 20000726-21342893

P46 is the European patent published by the Japanese company Imura Kaku, entitled 'Wind-driven vessel'. NP46 characteristics are give in Table 5.7.NP46.

Table 5.7.NP46. Characteristics

Number of vertices (n)	**3**
	Arcs
Total number of lines	2
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.22
Average degree	1.33

In-degree centrality (Figure 5.1.NP46, Table 5.8.NP46) – P46 is the most cited patent of NP46, the other two vertices have no citations.

Table 5.8.NP46. In-degree and out-degree centrality values of NP46

Rank	**In-degree centrality**			**Out-degree centrality**		
	Vertex	**Value**	**Id (Label)**	**Vertex**	**Value**	**Id (Label)**
1	1 (P46)	2	20000726-21342893	3	1	20091119-71921967

2	2	1	20061116-29535910

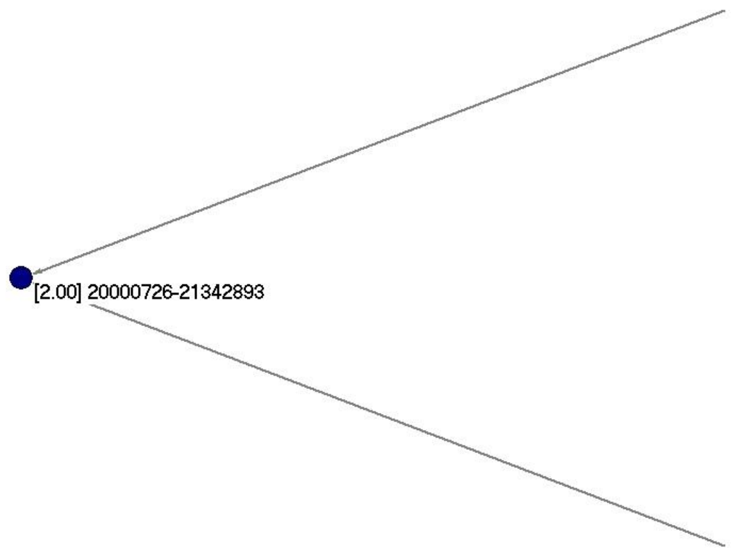

Figure 5.1.NP46. In-degree centrality of NP46

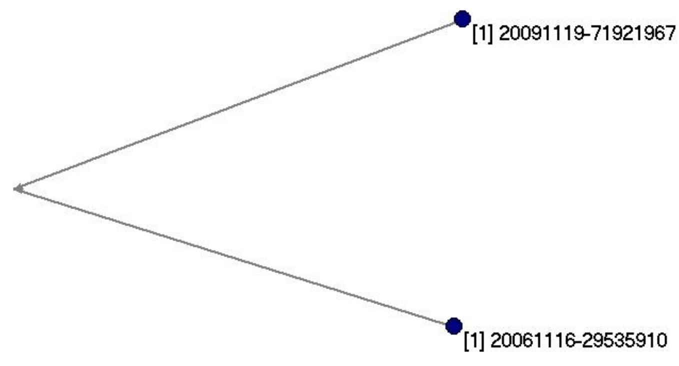

Figure 5.2.NP46. Out-degree centrality of NP46

Closeness centrality (Figure 5.3.NP46; Table 5.9.NP46) – P46 is the first among the three patents according to the closeness centrality measure. This means that it is near to the centre of local clusters and is relatively close to all the others. The concept is more intuitively explained by Figure 5.3.NP46, which shows P46 lying at the centre of the surrounding clusters.

Table 5.9.NP46. Closeness centrality values of NP46

Rank	Vertex	Value	Id (Label)
1	1 (P46)	1	20000726-21342893
2	3	0.67	20091119-71921967
3	2	0.67	20061116-29535910

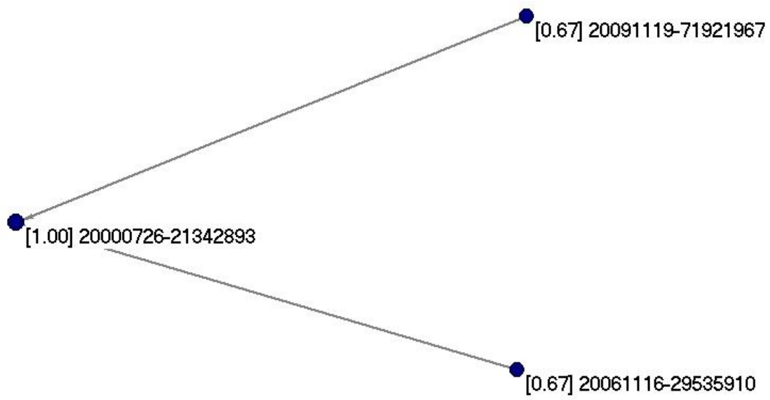

Figure 5.3.NP46. Closeness centrality of NP46

Authority weights (Figure 5.4.NP46, Table 5.10.NP46) – P46 is the only authority of NP46.

Table 5.10.NP46. The authority patents of NP46

Rank	Vertex	Value	Id (Label)
1	1 (P46)	1	20000726-21342893

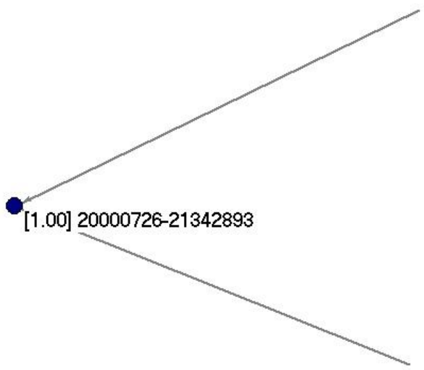

Figure 5.4.NP46. The authority patents of NP46

<u>*Hub weights (Figure 5.4.NP46, Table 5.11.NP46)*</u> – The other two patents of NP46 are the two hubs of the authority P46.

- Vertex 3 was published simultaneously in several different countries by Propit AB, with the title 'Ship comprising wind power stations for manoeuvring and powering the ship and a method for manoeuvring such a ship';
- vertex 2 was published simultaneously in several different countries by a Greek inventor, with the title 'Fan of radial blades of variable pitch with ring, fixed on boat'.

Table 5.11.NP46. The hub patents of NP46

Rank	Vertex	Value	Id (Label)
1	3	0.71	20091119-71921967
2	2	0.71	20061116-29535910

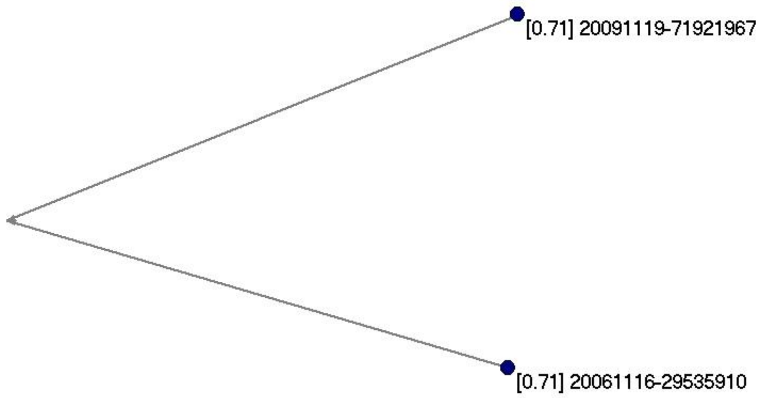

Figure 5.4.NP46. The hub patents of NP46

SPC (Figure 5.6.NP46, Table 5.12.NP46) – The NP46 technological trajectory comprises the three patents already described.

Table 5.12.NP46. Vertices on main path [flow] of NP46

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000726-21342893
2	2	1	20061116-29535910
3	3	1	20091119-71921967

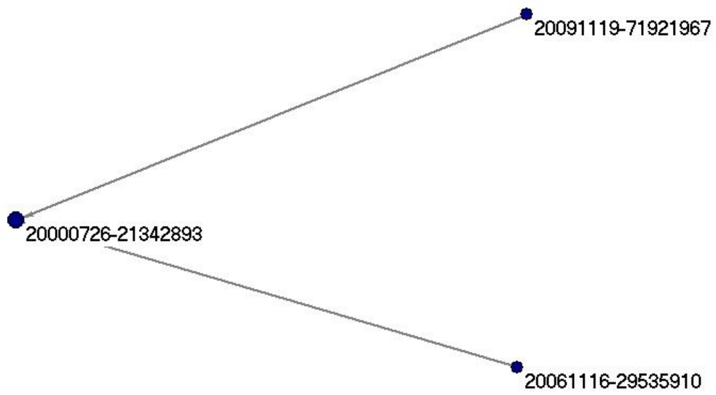

Figure 5.6.NP46. SPC of NP46

Network and connectivity analysis of network built on P49 (NP49)- 20000315-21361038

P49 is a European patent published by the Japanese TDK Corporation, with the title 'Solar cell module' (IPC: H01L31/042). NP49 characteristics are given in Table 5.7.NP49.

Table 5.7.NP49. Characteristics

Number of vertices (n)	**115**
	Arcs
Total number of lines	135
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.01
Average degree	2.34

In-degree centrality (Figure 5.1.NP49, Table 5.8.NP49) – According to the in-degree centrality values P49 is the 4th most cited patent. The most cited is vertex 3, owned by the Japanese

Semiconductor Energy Laboratory, with the title 'Solar cell and method for fabricating the same'.

Table 5.8.NP49. Top 10 in-degree and out-degree centrality values of NP49

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	3	13	20020903-66314895	31	4	20100722-73856832
2	44	10	20110308-74930119	14	3	20080311-61273973
3	8	8	20061031-65599336	13	3	20071120-63867001
4	1 (P49)	7	20000315-21361038	93	3	20120802-80362911
5	7	7	20060720-62290887	105	2	20121127-63845650
6	23	7	20100225-72682175	11	2	20070522-66652107
7	33	7	20100930-74621952	94	2	20120807-74317070
8	31	6	20100722-73856832	45	2	20110322-71533489
9	15	5	20080429-61399904	4	2	20030218-66314879
10	27	4	20100511-70692572	77	2	20120501-63452956

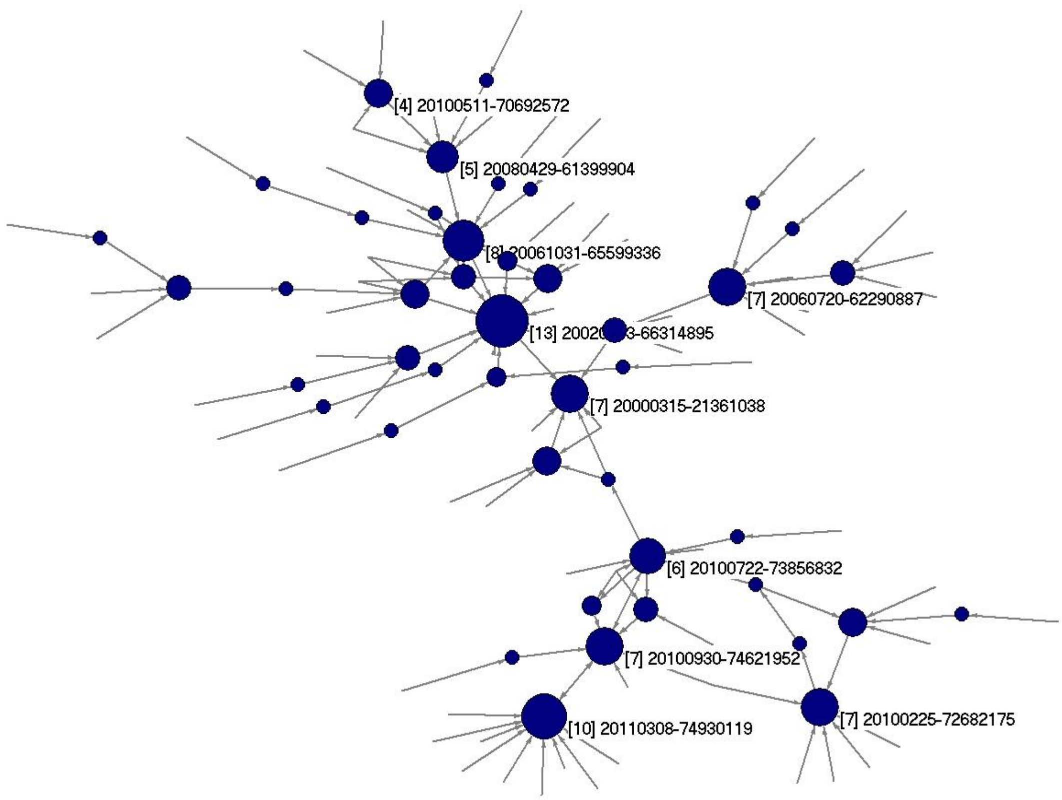

Figure 5.1.NP9. In-degree centrality of NP49

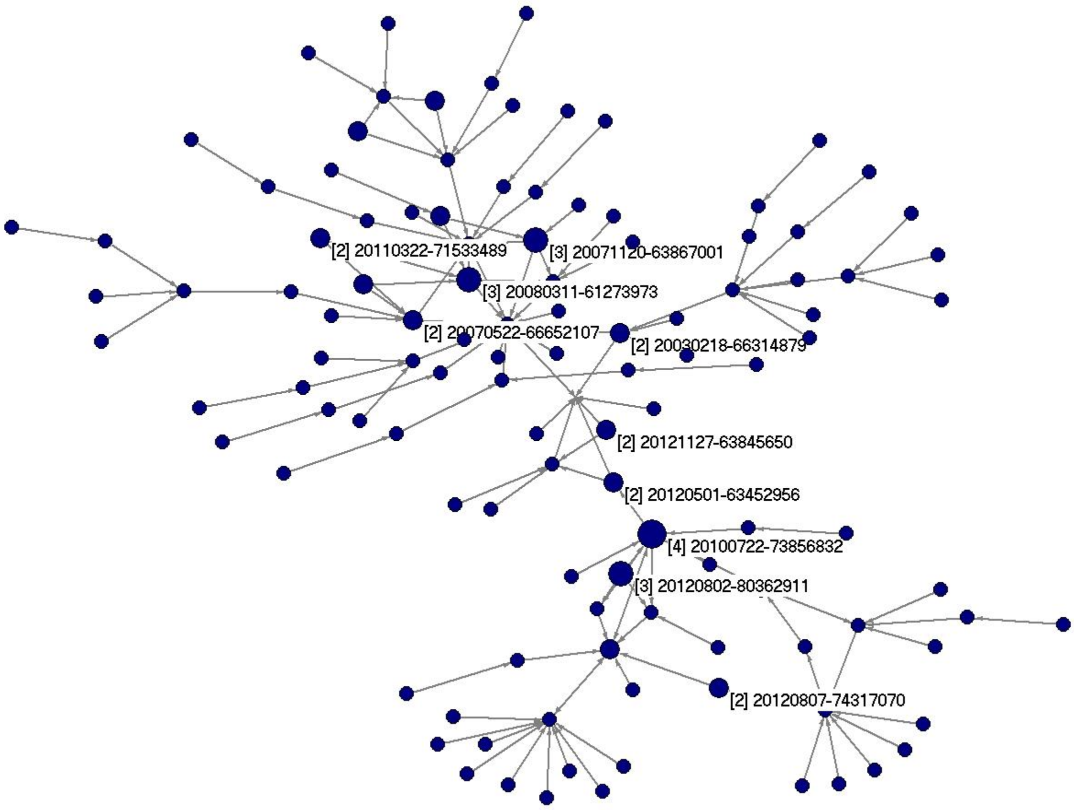

Figure 5.2.NP49. Out-degree centrality of NP49

<u>*Closeness centrality (Figure 5.3.NP49, Table 5.9.NP49)*</u> – P49 is ranked 2nd for closeness centrality, after vertex 3 which is also the most cited patent according to the in-degree centrality values.

Table 5.9.NP49. Closeness centrality values of NP49

Rank	Vertex	Value	Id (Label)
1	3	0.29	20020903-66314895
2	1 (P49)	0.28	20000315-21361038
3	4	0.27	20030218-66314879
4	77	0.26	20120501-63452956
5	8	0.25	20061031-65599336
6	11	0.24	20070522-66652107
7	12	0.24	20070605-62860551
8	14	0.24	20080311-61273973
9	31	0.24	20100722-73856832
10	13	0.24	20071120-63867001

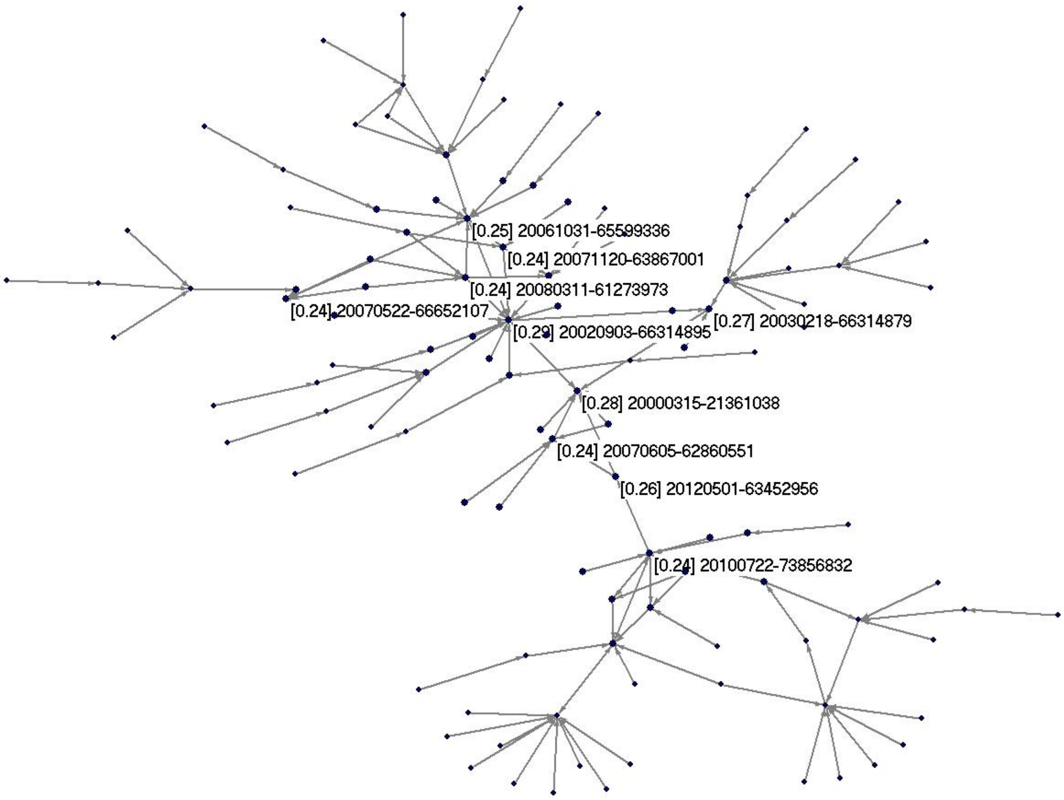

Figure 5.3.NP49. Closeness centrality of NP49

<u>*Authority weights (Figure 5.4.NP49, Table 5.10.NP49)*</u> – P49 is not one of the highest authority patents.

- the first ranked authority in NP49 is vertex 44, owned by the American company IB Roof Systsems, with the title 'Method for securing flexible solar panel to PVC roofing membrane' ;
- the second ranked authority patent is vertex 31, owned by the American CertainTeed Corporation, with the title 'Photovoltaic roof covering';
- the third ranked authority patents is vertex 14, owned by the American company Micron Technology, with the title 'Masking structure having multiple layers including an amorphous carbon layer';

- the fourth ranked authority patent is vertex 33, owned by the CertainTeed Corporation with the title 'Photovoltaic systems, methods for installing photovoltaic systems, and kits for installing photovoltaic systems';
- the fifth ranked authority patent is vertex 87owned by the CertainTeed Corporation, with the title 'Photovoltaic systems, methods for installing photovoltaic systems, and kits for installing photovoltaic systems'. Note that the last two are different patents, published in different years, despite having the same title and owner.

Table 5.10.NP49. The authority patents of NP49

Rank	Vertex	Value	Id (Label)
1	44	0.94	20110308-74930119
2	31	0.26	20100722-73856832
3	14	0.11	20080311-61273973
4	33	0.07	20100930-74621952
5	87	0.07	20120607-79843171
6	92	0.06	20120802-80362908
7	11	0.06	20070522-66652107
8	13	0.05	20071120-63867001
9	38	0.04	20101026-72030361
10	23	0.03	20100225-72682175

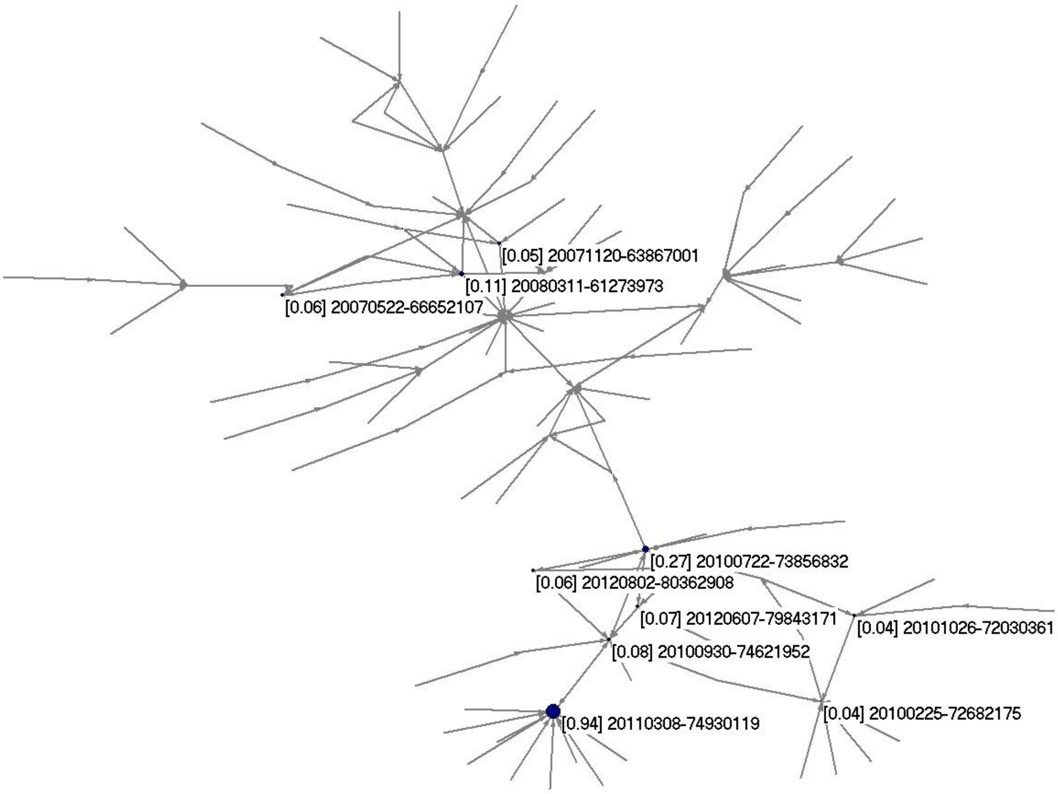

Figure 5.4.NP49. The authority patents of NP49

<u>*Hub weights (Figure 5.4.NP49, Table 5.11.NP49)*</u> – The top 10 hubs listed in Table 5.12.NP49 are all developments of the first authority patent, as shown in Figure 5.4.NP49. The top five are:

- vertex 33, already mentioned as the fourth authority patent;
- vertex 100, owned by the American company Vermont Slate & Copper Service, with the title 'Roofing grommet forming a seal between a roof-mounted structure and a roof';
- vertex 95, owned by the American company Vermont Slate & Copper Service, with the title 'Roofing grommet forming a seal between a roof-mounted structure and a roof'. Note that this and the above patent have the same title and owner, but are different;

- vertex 91, owned by the American company Vermont Slate & Copper Service with the title 'Roofing system and method';
- vertex 90, owned by the American company Vermont Slate & Copper Service, with the title 'Roofing grommet forming a seal between a roof-mounted structure and a roof'.

Table 5.11.NP49. The hub patents of NP49

Rank	Vertex	Value	Id (Label)
1	33	0.39	20100930-74621952
2	100	0.29	20120925-79443841
3	95	0.29	20120821-79037954
4	91	0.29	20120724-79036388
5	90	0.29	20120703-76742684
6	84	0.29	20120522-79038055
7	79	0.29	20120501-79038106
8	72	0.29	20120410-77821787
9	71	0.29	20120410-75404327
10	69	0.29	20120403-77821789

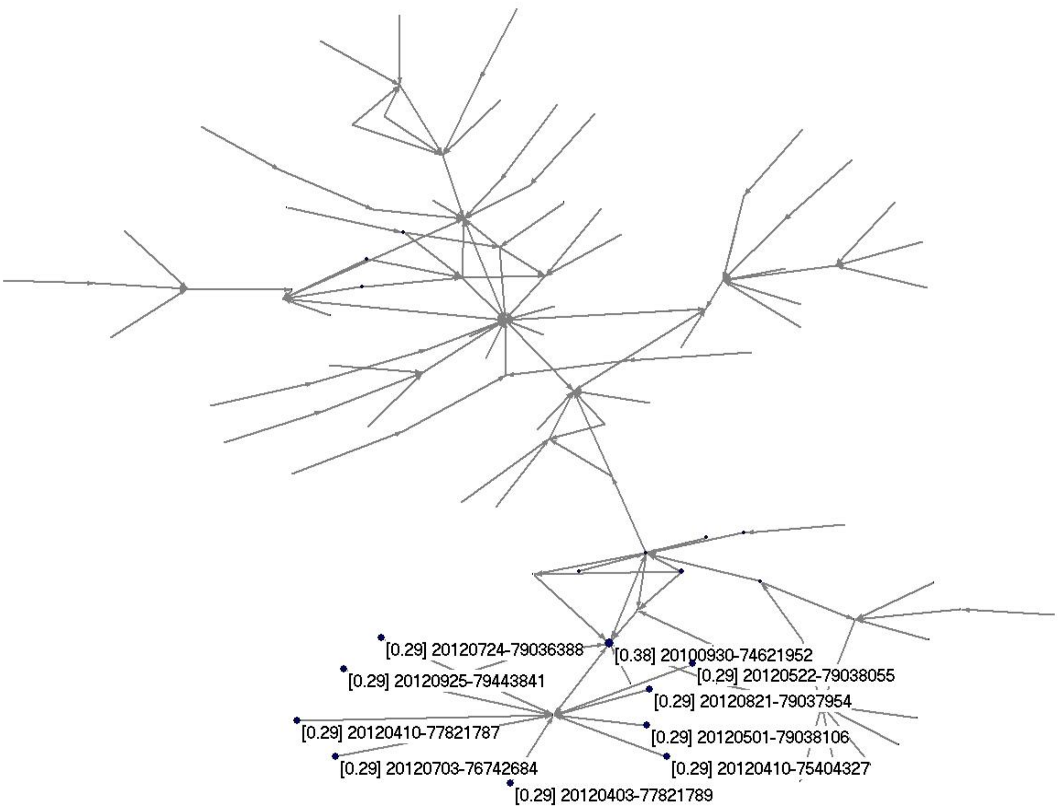

Figure 5.4.NP49. The hub patents of NP49

SPC (Figure 5.6.NP49, Table 5.12.NP49) – The SPC algorithm highlights eight patents that comprise the technological trajectory of NP49. This goes from P49 to vertex 67, owned by the Japanese company Elpida Memory, with the title 'Semiconductor device having contact plug and manufacturing method thereof'. Between the two is a network of six patents:

- the most cited vertex 3;
- vertex 8, published in the US by the American Micron Technologies, with the title 'Masking structure having multiple layers including an amorphous carbon layer';
- vertex 9, published in the US by the American Micron Technologies, with the title 'Transparent amorphous carbon structure in semiconductor devices';
- the third authority patent vertex 14.

Table 5.12.NP49. Vertices on main path SPC [flow] of NP49

Rank	Vertex	Cluster	Id (Label)
1	1	1	20000315-21361038
2	3	1	20020903-66314895
3	8	1	20061031-65599336
4	9	1	20061107-65601620
5	13	1	20071120-63867001
6	14	1	20080311-61273973
7	32	1	20100727-64279218
8	67	1	20120306-72683527

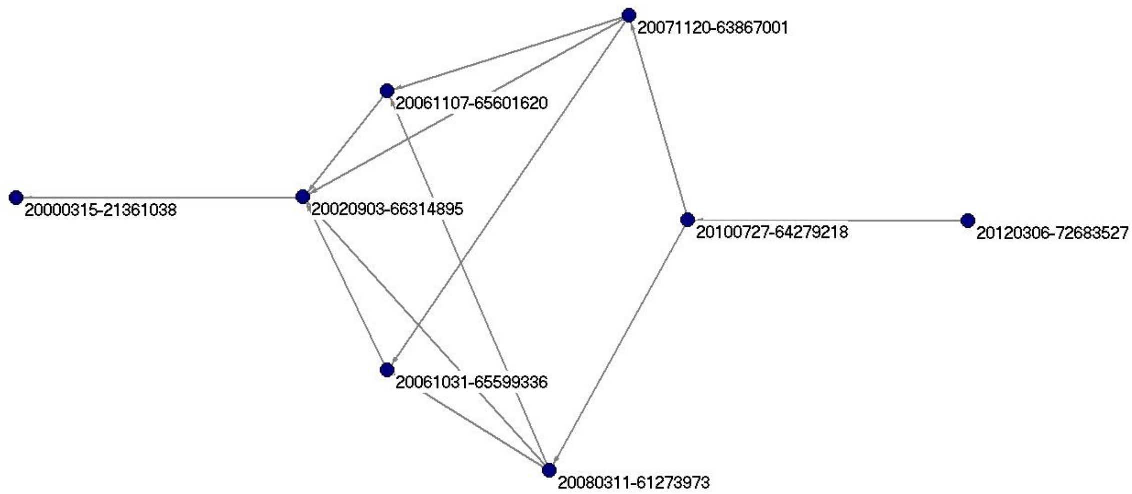

Figure 5.6.NP49. SPC of NP49

Network and connectivity analysis of network built on P52 (NP52) - 20001220-21380631

P52 is a European patent owned by the Swiss company Enecologo AG, entitled 'Frame made for shaped sections and designed for plate-like elements, and array of several such frames' (E04F13/08, H01L31/042). NP52 characteristics are given in Table 5.7.NP52.

Table 5.7.NP52. Characteristics

Number of vertices (n)	**2**
	Arcs
Total number of lines	1
Number of loops	0
Number of multiple lines	0
Density [loops allowed]	0.25
Average degree	1.00

In-degree centrality (Figure 5.1.NP52, Table 5.8.NP52) - P52 is the only one of the two patents to receive a citation.

Table 5.8.NP52. In-degree and out-degree centrality values of NP52

Rank	In-degree centrality			Out-degree centrality		
	Vertex	Value	Id (Label)	Vertex	Value	Id (Label)
1	1 (P52)	1	20001220-21380631	2	1	20121128-79741442

Figure 5.1.NP52. In-degree centrality of NP52

Figure 5.2.NP52. Out-degree centrality of NP52

Closeness centrality (Figure 5.3.NP52, Table 5.9.NP52) – According to the closeness centrality measure the two patents are equally important.

Table 5.9.NP52. Closeness centrality values of NP52

Rank	Vertex	Value	Id (Label)
1	1 (P52)	1	20001220-21380631
2	2	1	20121128-79741442

Figure 5.3.NP52. Closeness centrality of NP52

<u>*Authority weights (Figure 5.4.NP52, Table 5.10.NP52)*</u> – P52 is the authority patent in NP52.

Table 5.10.NP52. The authority patents of NP52

Rank	Vertex	Value	Id (Label)
1	1 (P52)	1	20001220-21380631

Figure 5.4.NP52. The authority patents of NP52

<u>*Hub weights (Figure 5.4.NP52, Table 5.11.NP52)*</u> – The second vertex is the hub of NP52. It was published in Europe by a Swiss private inventor, with the title 'Cladding system for cladding the external surface of a building'.

Table 5.11.NP52. The hub patents of NP52

Rank	Vertex	Value	Id (Label)
1	2	1	20121128-79741442

Figure 5.4.NP52. The hub patents of NP52

SPC (Figure 5.6.NP52, Table 5.12.NP52) – These two patents constitute the technological trajectory of the small NP52.

Table 5.12.NP52. Vertices on main path [flow] of NP52

Rank	Cluster	Id (Label)
1	1	20001220-21380631
2	1	20121128-79741442

Figure 5.6.NP52. SPC of NP52