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AN EXTENDED METHODOLOGY FOR THE ASSESSMENT OF TECHNICAL INVENTION EVOLUTION

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1. Introduction

The development of new technologies is one of the main objectives of today's scientific and industrial development. The companies that are operating in a competitive global environment are trying to improve their development processes, develop new products or to offer new services to the market based on improved or new technologies to attain a dominant and advantageous position in the market. Accordingly, current research trends focused on emerging technologies, and their development based on technical inventions, represent an increasingly important part of research and systematic efforts in both academia and the industry [Solé et al. 2013]. Determining the direction of technology development is an approach used in the industry to support strategic and long-term planning of the development of products, processes, and services. The purpose of gaining a precise understanding and description of the dynamic relationship between technical inventions, their implementation in physical systems and services and market development for such innovation, is to determine (predict) the future direction of technology development. Organizations that operate in highly competitive market conditions have a need for up-to-date knowledge of emerging technologies [Dedehayir et al. 2014] to timely plan the improvement and introduction of new products or services into the market or internal changes in production and other business processes. Research on the conditions and manner of the new technologies emergence and the study of the dynamics of technology development are important in theoretical as well as practical terms. The aim of the research presented in this paper is to propose an extended methodology for the assessment of the invention evolution in a contemporary socio - technical context. The proposed methodology will in future research be coupled with the development of the model for technology readiness level development in a framework for the technology prediction with the goal to reduce the uncertainty of decision-making in development projects.

Within this article, the authors will present the early result of the study focusing on the evolution of the technical invention by using patents as a proxy for technology development. The rationale for using patents as the basis for studying technology development is its pervasiveness as the intellectual property related communication and feasibility of analysis. In looking at the dynamics, the presented research will focus on the patent citation network representing the evolution within particular patent class describing the scope and context, while, in the next step, the dynamics of the patent content network will be explored representing the language of the invention.

The rest of the paper is structured as follows: Section 2 give a review of the state of the art, Section 3 describes a proposed methodology for patent analysis, Section 4 discusses results from an initial case study while Section 5 brings conclusions.

2. State of the art

The literature describes two models of the technology evolution: continuous and discontinuous [Sood et al. 2012]. Researchers who advocate a model of continuous and incremental evolution of technology [Dosi 1982], [Wollin 1999] claim that this process is constantly in a state of recombination and synthesis based on elements of existing technology, and argue that improvement of the performance of technology in these activities are a result of changes in perception, values, culture, organizational structure, resources and core competencies of the people who work in development as well as society as a whole. For them, innovation is a social process based on the accumulation of small improvements, and not on the significant contributions of brilliant individuals. Researchers who advocate a model of the discontinuous evolution of technology [Veliyath and Shrivastava 1996], [Hoisl et al. 2014], [Solé et al. 2014] claim technology improves through periods of incremental improvements that are dotted with discontinuous shifts. They claim that the products and services that are based on entirely new technical inventions create significant progress and, when implemented, become the leading technology innovation resulting in a discontinuous shift. In presented research, the evolution of patents is used as a proxy for the technology development. Patented inventions can be seen as bundles of distinct technologies brought together to accomplish a particular outcome [Strumsky et al. 2012]. They leave behind a detailed evidentiary trail, and consequently, patenting activity has become a widely used environment for studying the "intellectual capital economy" [Strumsky et al. 2012]. As such, intellectual property protection is one of the key steps in technology evolution process (Figure 1).

Figure 1. Technology evolution circle

By analysing how patents are built on each other, their evolution can be explored and analysed. If carefully examined, patents can provide insight into technology, reveal business trends, inspire novel industrial solutions and help decide investment policy [Lee et al. 2009]. Therefore, in the research present in this paper, the patents are considered a primary source of information to be analysed within presented methodology to get insights and gain the understanding of technology evolution.

2.1 Elements of patent description

In general, all patent descriptions contain information about the inventors, the patent classes assigned to the patents (according to International Patent Classification - IPC), information about previous patents the current patent cites, as well as the dates relevant for patent lifecycle [Griliches 1990]. The WIPO (World Intellectual Property Organisation) identify the technology elements constituting invention through an elaborate system of technology codes that categorize the features of a patented invention. The novelty of an invention is described by its inventor, with technical and precise details, in the patent's claims. At any given timestamp, the existing set of technology codes available to a patent examiner is essentially a description of the state of the art technological capabilities [Lee et al. 2009]. These codes make it possible to group patents according to similarly of the claimed subject matter making them easier to search and find [Strumsky et al. 2012]. The summary of a patent is also important when conducting the patent evolution analysis because it can be used to extract keyword relevant to the subject. In the course of here presented research, the key elements of the patent in focus are: publication

date, the patents it cited and was cited by, the codes used to classify it, and the keywords used to describe the patent.
Patent evolution is in literature studied mostly by application of quantitative methods. Quantitative methods use different metrics (growth, diffusion, power) to explore invention development. The advantage of using quantitative metrics is that the results provide more precise insight then qualitative methods since qualitative methods enable interpretation in the different ways. Another advantage of quantitative methods is that results from multiple cases can be easily compared. Therefore, various technologies can be analysed and compared in a way that doesn't rely heavily on the interpretation of examiner. A qualitative method used to study patent evolution result mainly in a creation of the different type of patent maps. However, combined with other data, namely patent publication date, dynamic maps can be created which is a combination of both qualitative and quantitative approaches.

2.2 Patent growth, diffusion speed and power

The quantitative methods based on the number of patents are used to identify the technology life cycle (TLC) stage of a particular technology. In the work of Gao et al. [2013] four stages were introduced as is shown in Figure 2. The authors in [Gao et al. 2013] discuss diversifying the sources for the life cycle analysis. They mention 13 different indicators used to identify the life cycle of technology like for example number of patents by application year, the number if IPCs by priority year, the number of backward citations to patents in priority year, etc. While using the S-curve to describe the technology life cycle is not a novel approach, and is similar to other methods, for example the Utterback-Abernathy model [Utterback et al. 1975] that links the rate of innovation with a specific phase of innovation, it is still considered one of the most relevant methods to explore a technologies life cycle.
As it can be seen from Figure 2, the life cycle of technology can usually be approximated with an S-curve created by a number of accumulated patents. By analysing the technologies position on the S-curve, it is possible to deduce if the technology is worth investing. Researchers do not recommend investing in an invention and technology during the initiation and saturation stages and instead recommend investing during the growth phase [Altuntas et al. 2015]. Moreover, by analysing a current position on the S-curve, it is possible to gain insight about the speed of future technology development. For example, a technology at the start of growth phase may be expected to develop faster than if it was at the beginning of its saturation period.

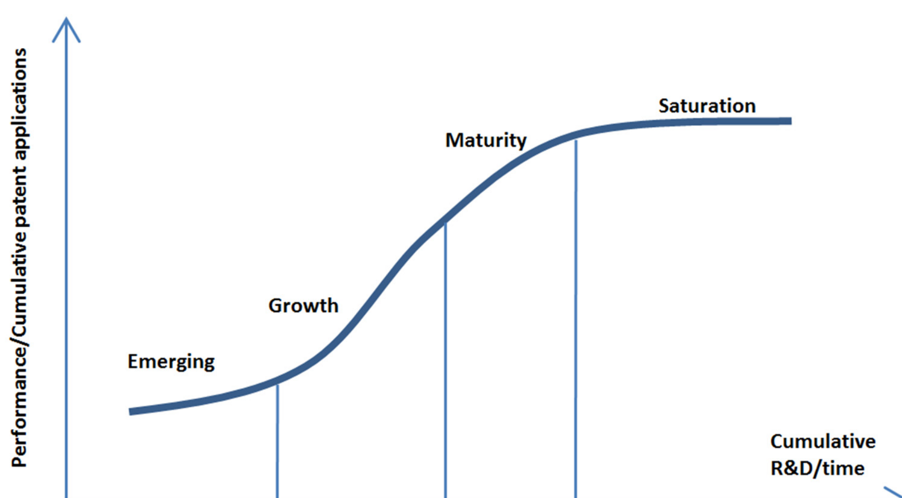


Figure 2. S-Curve of TLC [Gao et al. 2013]

When discussing technology diffusion, a knowledge spillover caused by patent citation is considered [Altuntas et al. 2015]. If a patent is cited by other patents, it is probable that the cited patent is valuable and, therefore, has a higher chance of subsequent diffusion as well as technology that will be created based on the invention. Altunas et al. define patent diffusion speed (PDS) as:

$$PDS = \frac{a}{b} \quad (1)$$

where a is the total number of forward patent citations and b is the total number of examined patents that are considered for diffusion. A higher diffusion speed may imply that the technology that is described as an invention in patents has a greater market potential. Specifically, it means that such technology may influence other technologies in the near future thus making it a potentially good investment.

Altunas et al. [2015] also define technology scope as the breadth of technology. If this breadth is high, the technology has associations with a lot of different technologies. Technology scope is measured by two indicators, patent power (PP), and the expansion potential (EP). Patent power is defined by the expression:

$$PP = \frac{x}{y} \quad (2)$$

where x is the total number of IPC codes included in the set of examined patents and y is the total number of examined patents. A higher patent power (PP) is usually interpreted as the analysed technology having a strong association with other technologies and having a higher chance of creating new technology sectors. The expansion potential of technology (EP) increases as the number of IPC codes mentioned in the examined patent rises. A technology with a high technology scope has a potentially greater economic impact. Lerner [1994] claims that broad patents are more valuable when substitutes in the same product class are plentiful. He also shows that patents assigned to more IPC classes are more likely to be cited in subsequent patent documents.

2.3 Patent network visualisations

In addition to qualitative measures for assessment of the patent evolution, there are complementary visualization methods used for the patent analysis. Kim et al. [2008] define it as the visualized expression of comprehensive patent analysis results used to understand qualitatively complex patent information easily and efficiently. Notable examples of patent maps are the work of Tseng et al. who made patents maps for carbon nanotube technology [Tseng et al. 2007], Morris et al. who visualised chemical sensor patents [Morris et al. 2002] (Figure 3) and the work of Fattori et al. [2003].

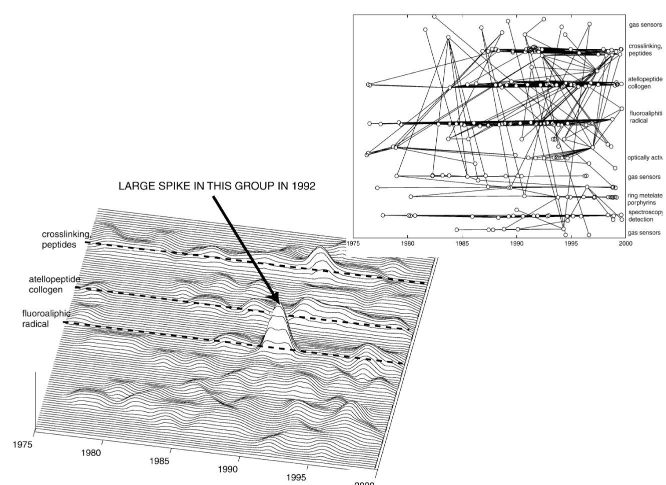


Figure 3. Timeline of chemical sensors patents [Moriss et al. 2002]

Previously mentioned patent elements can be classified as structured elements, which are uniform in semantics and format across a patent document (patent number, filing date, inventors) or unstructured elements that vary in content and context (free text: claims, abstracts, invention description). The visualizations of structured elements analysis results are called patents graphs while visualisations of

unstructured data are called patent maps [Tseng et al. 2007]. Yoon and Park [2004] argue that a well-constructed visualisation of patent elements often convey an intuitive knowledge of the structure of a technical system and provides valuable insight into the holistic nature of a set of examined patents.
From the existing literature, it can be concluded that there exists interest in leveraging visualization techniques that allow the mapping of patent dispersion patterns. In addition to visualizing the structure of existing patent citation networks, it is necessary to explore different aspects of patent citation dynamics to find meaningful and predictive patterns of evolution trends.

3. Proposed methodology

The aim of the research presented in this paper is to propose the extended methodology for comprehensive technical invention evolution analysis as the first step towards the understanding of the evolution of a targeted technology. Figure 4 presents an overview of the methodology steps.

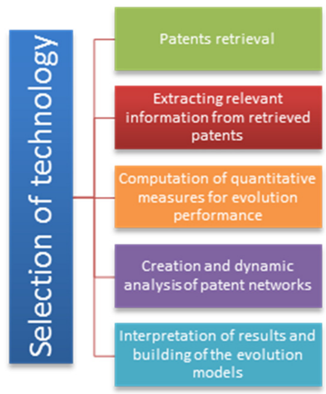


Figure 4. Overview of the proposed methodology

After choosing a technology to analyse, relevant patents should be retrieved. This is followed by extraction of the relevant data and contextual information from the patent description. The first analysis step consists of the computation of the quantitative measures that are indicating the evolution performance. The following step is an extension to the existing qualitative approaches by the creation of patents citation and content networks accompanied with the combination of dynamic network analysis to reveal the nature of technical invention evolution. This step considers patent content in conjunction with citation data, to visually display technical invention evolution dynamics over time. Patent evolution visualization can provide a narrative for understanding the dynamics of invention creation, synthesis and recombination. The interactions between various patent citations are more than cumulative; it spawns new invention elements that can, in turn, generate new invention. While this organic process cannot be controlled, understanding its dynamics through visualisation and qualitative/quantitative network analysis can identify patterns of interactions through citations that can lead to innovation and success or conflict and failure. By visualising citation interactions over time, this approach allows for an improved understanding of mediated relationships between the patents within the particular patent class. Finally, the results of the analysis should be interpreted, and evolution models should be created. In each step, several methods can be used, and some of them are illustrated in the following case study.

4. Case study

The case study related to the sports technology was chosen to illustrate methodology and demonstrate usability and possible results. In the case study, the patents with the description of technical inventions related to yieldable or self-releasing ski bindings also known as safety bindings were explored. Google patents (https://patents.google.com/) was used as the primary source for patents retrieval. Accordingly to WIPO, the A63C9 classification code is related to the ski bindings, and A63C9/08 represents safety ski bindings that have been chosen for examination. 547 patents were found by Google patent search with given criteria. For every patent the following information has been extracted: Name, Grant, Priority

Date, Publication Date, Classification Codes, Patent Citation and Cited by. The information was extracted manually; every patent was individually examined and the relevant information was entered into a spreadsheet. In future research, this activity will be automated. Two dependency matrices were created from the extracted information as a starting point to build citation network. The first links patents to patents they quote while the second links patents to patents who quote them.

4.1 Understanding evolution performance

In the first step of analysis the starting point was the number of patents granted since the first patent with this code published in 1960. Number of patents per year is shown in Figure 5. An approximation of the S-curve based on the cumulative number of patents issued each year is shown in Figure 6.

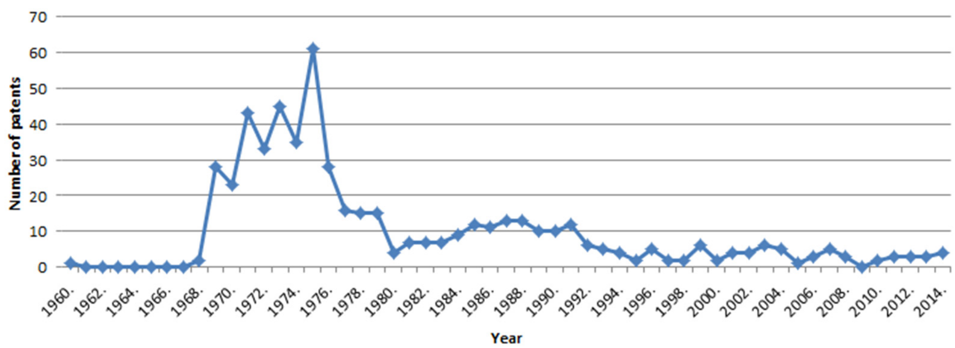


Figure 5. Number of patents for safety ski bindings applied yearly since 1960

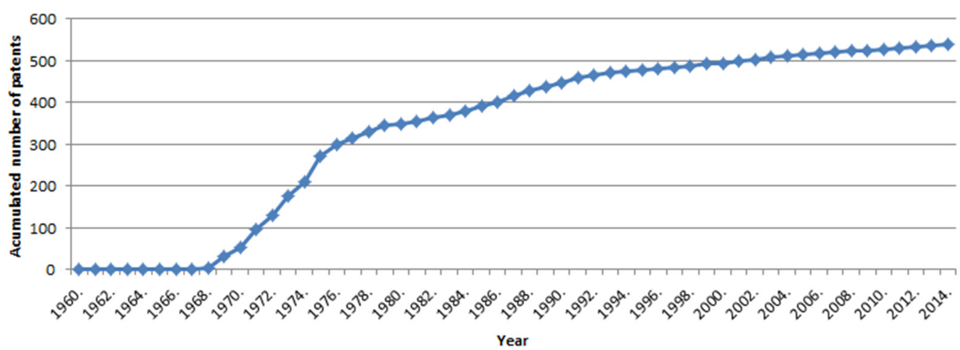


Figure 6. S-Curve of safety ski binding technology patents growth

From the Figures 5 and 6 it is possible to clearly identify the 4 phases of the technology life cycle: initiation (1960-1968), growth (1969-1975), maturation (1976-1978) and saturation (1976-2015). In order to calculate diffusion and power, the Table 1 summarises information about the total number of patents retrieved as well as the total number of patent.

Table 1. Number of patents and citations for ski bindings

Technology	Safety ski bindings
Total number of examined patents	547
Total number of citations	3850

The IPC classes used in description of the retrieved patents and their respected frequency (number of times they occur in the patents) are shown in Table 2.

Table 2. IPC classes for patents related to safety ski bindings and their frequency

No.	IPC code	Frequency
1	A63C	539
2	A43B	6
3	B01F	1
4	A61B	1
5	A61D	1
6	B61D	1

As was mentioned before, the patent diffusion speed and power are the metrics used to compare multiple technologies. To get the sense about results for examined technology, they were compared to the results given in the work of Altunas et al. for some other technologies (Table 3).

Table 3. Comparison of ski bindings with results for different technologies (source: [Altunas et al. 2015])

Technology	Diffusion speed	Patent power
TFT-LCD	10,61	1,73
Flash memory system	31,11	1,3
Personal digital assistant	31,46	1,38
Safety ski bindings	7,03	1,004

Compared to the results for other technologies, safety ski bindings have a relatively low diffusion speed and patent power. This means that, compared to the other technologies, safety ski bindings in their current lifecycle phase are a poorer choice for an investment or further development without radical innovation as they have the lowest diffusion speed and patent power.

4.2 Discrete-time citation network visualisation and network growth analysis

For the purpose of the case study, the patent citation network is generated and continuously recalculated whenever new patent within the class is added inspired by work of Cash et al. [2013]. Patents in the citation network represent nodes, and edges represent the citation of the other patents that are existing within the class. This allows for an animated visualisation of the network over time, illustrating the dynamics and evolution of the citation network as new patents are added to the picture. Both continuous and discrete network growth dynamics are used for the analysis, with the latter taking into account network configuration snapshots for each of the key TLC periods identified previously, showing the emerging evolution over the overall study. For the presentation in this paper, the authors generated two sets of images (without and with community detection in the network) for particular time point of network evolution (Figure 7).

Within the citation network, it can be seen that several patents created a star-network communities pointing to the hypothesis that the invention evolution process for particular case was driven mainly by popularity bias, as continuous improvement of the few key inventions. This can be proved by examining the degree distribution of the nodes in a network. Powell et al. have described different types of network nodes' degree distributions that can be distinguished when plotted on a log-log scale, with the degree on the x-axis and the number of nodes with this degree on the y-axis [Powell et al. 2005]. The degree distribution for a network in which the formation of edges is governed by a popularity bias (i.e. nodes with more connections have a higher probability of new connections) can usually be approximated with the straight line on the log-log chart.

In Figure 8a the x-axis reflects degree D (aggregated over overall time period of the study) and the y-axis the number of patents having a given degree N (also aggregated over overall time periods) for citation network. Dark blue coloured segmented line is presenting the same within the bins of degrees being normalised to growing exponentially, and black line presents the trend line linear approximation for the normalised distribution. Since these degree distributions are aggregate measures over all time periods, they provide insights about the network growth process. Based on the distribution represented on the Figure 8a the authors found that citation was governed by a popularity bias distribution, indicating the importance of the 'key patents that represent the core of the invention evolution for examined technology.

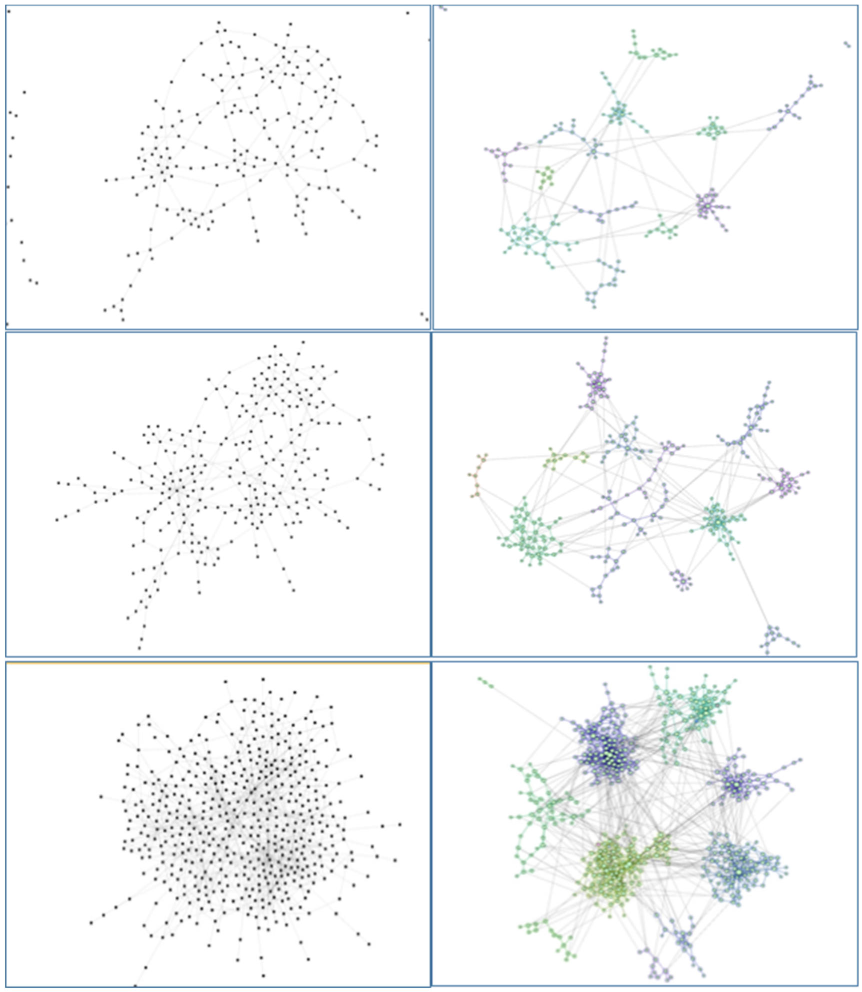
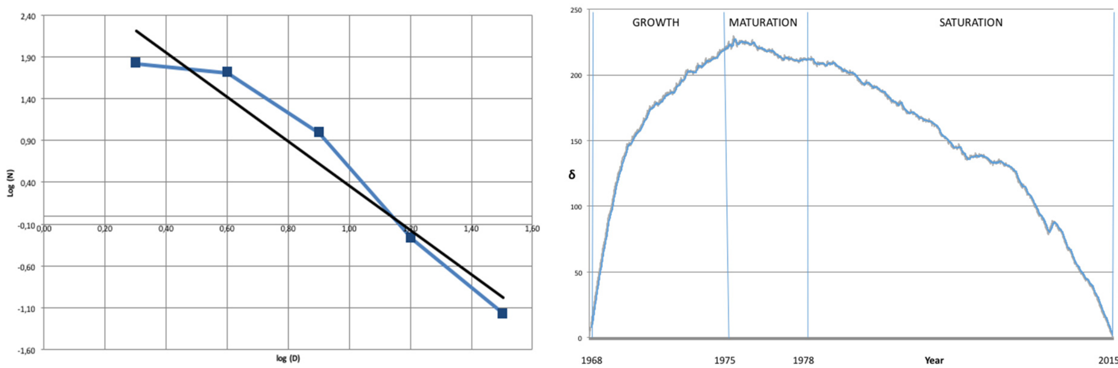


Figure 7. Evolution of the patent citation network for ski bindings depicted by network configuration after key TLC phases (growth (1975), maturation (1978), saturation (2015)

In addition, the rate of growth δ of the network's edges in respect to network's nodes over time was analysed by using method proposed by Cash et al. [2013]. This provides insights on network formation and growth dynamics, such as identifying the most critical growth phase or phases in which a shift in evolution occurred in citation network. The positive trends in growth analysis are corresponding with dominant addition of the new nodes into the network, and negative trends with dominant rewiring (citation) of the existing nodes. Together with the nodes' degree and measures such analysis provide substantial insights on the impact of individual patents to overall network growth dynamics.

The results of the relative network growth analysis applied to the patent citation network are shown in Figure 8b. It can be seen that during the growth phase, more new patents are introduced than citations are added causing the constant growth of the network structure. In the following period (maturation) the number of new patents introduced equals the number of citation creating a mainly neutral trend. In the saturation phase, more citations among the patents are provided than new inventions are added which is reflected by negative trend of network growth indicating the saturation.

Single-case studies are limited in their applicability beyond their particular contexts. This study is no exception. However, the results of this study indicate that structure of citation network for examined technology exhibits hierarchical and centralised tendencies when is considered through the evolving body of the patents within the technology class. Citation structure visualisation allows for an aggregate dynamic analysis of the inventions that are created through discrete contributions in a network. Combined with quantitative performance measures, sheds light on what factors were influencing the invention evolution specific for the particular technology.



Degree distribution **b) Relative growth analysis**

Figure 8. Dynamic network analysis of patent citation network for ski bindings

5. Conclusion

In this paper, the authors presented an extended methodology for visualising the dynamics of patent-based knowledge citation networks as the first step towards overall framework for prediction of technology development. As presented, there are three main research implications from this work. First, by displaying the dynamics of rather a large collection of the patents reflecting the patent citation structure over the time, this methodology allows better insights into the evolution of invention from patent content perspective. Further, the methodology provides rich qualitative and quantitative perspective on patterns of patent citation in the form of the network visualisations. In addition to this contribution, by providing the means to carry out network growth analysis of patent citation dynamics, presented extended methodology provides a means for probabilistically modelling patterns of technology evolution in the future. This methodology could prove invaluable in the conceptual phase of design when alternatives for a certain subsystem are being considered. An insight into related technologies could prove designers with multiple solutions when trying to design a subsystem that should perform a certain function.

Despite the strengths of the proposed methodology, there are some limitations that should be considered. Primarily, the applied statistical analysis is contextual, showing only the magnitude of change in the observed network. As such, there are difficulties associated with establishing what exactly this data means on a given dataset and how this might affect attempts to use this data to change the invention process in practice. Also, one case certainly cannot lead to the generalisations. As such, it is envisioned that further validation work should be in the exploration of methodology application in different contexts for different inventions evolution.

Additionally, the way patents were retrieved and how patent information was gathered, was done completely manually for this study. While this is feasible when examining a technology with a relatively small number of patents, it tough to apply to technologies with a big number of patents. Therefore, future research should focus on integrating an automatic text mining approach that would retrieve patent information in a more satisfactory way combined with automatic content processing techniques, tailored for exploration of the patent content networks and recognition of relevant contextual insights about function, structure, or actions within described invention. Only in that way, the methodology could be taught as a proper first building block of the technology prediction framework as was described in the introduction.

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