Visualization of nano risk research field to clarify domains year by year

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Abstract. With rising interest of nano technology R&D, nano risk researches have been greatly studied recently. They attract much attention since influence of nano products in the society is not well-known. Now the current state of nano risk research field is not fully investigated, and the object is overviewing this structure until 2008 and predicting the direction of next-coming studies. Nano risk 1611 papers were searched out with certain query and further refinement. And these papers were clustered by bibliometric method. The selected papers were clustered to seven parts and visually seen as aggregated blocks. Each cluster was labeled with proper name by analyzing in detail and the content of each cluster was classified with three terms, i.e. “Material”, “Hazard” and “Kinetics”. The biggest cluster was cluster #0 “atmospheric nanoparticles”, and secondly cluster #1 “nanoparticles used in imaging”, thirdly cluster #2 “toxicity of manufactured nano materials”. Furthermore, historical trend of the number of papers of each cluster was studied year by year. From the all results, short-term future predicting was performed by examining titles of papers or transition of the number of papers in each cluster and by watching the cluster position and gaps between clusters.

1. Introduction

The rapid development of nano science and engineering in the wide range of research fields and industries resulted in various nano-products such as nano-composite, drug delivery system (DDS), and nano-cosmetics. However, the influence of nano-materials in the environment including humans begins to be feared. Therefore, nano risk is recently recognized as a research target and strongly needed now. Furthermore, the analysis of outputs from nano risk researches is desired for the development/design of risk management. To achieve it the current situation survey of nano risk research and forecast for the future is necessary, but it has not yet been done in nano risk.

The purpose of this study was to investigate the current structure of nano risk research field by bibliometric method and to understand what domains are included in the field.

The bibliometric approach is a technique to obtain a whole perspective or state of a large research field. Nano science and engineering is one typical example having been developed rapidly with huge amounts of papers since the 1990s. While one option to assess emerging technologies is expert-based roadmapping [1], a computer-assisted approach is more helpful to see global research trends. Braun
focused on the scientific aspects of nanotechnology and described the rapid development since the early 1990s [2]. They could establish an exponential growth of publications in nanoscience and nanotechnology starting in the early 1990s. Meyer characterized the field as more interdisciplinary than other areas of science and explored the contributions by various fields of science and technology to nanoscience [3]. Meyer studied the interrelationships between science and technology [4, 5]. Meyer investigated co-author maps of nanoscience [6], while Calero proposed an author/organization combination and investigated clusters of authors to detect potential partners with similar activities [7]. Chau constructed a web portal about nanotechnology [8]. Huang monitored the research status of nanotechnology based on descriptive statistics and a citation network of countries, institutions, and technology fields [9-11]. Other researches also investigated nanotechnology by bibliometric methods [12-18].

2. Data and Methods

2.1. Data

Defining a research domain via a set of queries is not a rudimentary task [19]. In this paper, we used the following as queries to define nano risk:

\[
(A \text{ and } B) \text{ or } (A \text{ and } C) \text{ or } D
\]

where \(A\) denotes "nano* or ultrafine", \(B\) denotes “toxic*”, \(C\) denotes "exposure or dose or injection or administration or inhal", and \(D\) denotes “nano* and risk”.

We collected citation data on publications from the Science Citation Index (SCI) and the Social Sciences Citation Index (SSCI), compiled by the Institute for Scientific Information (ISI), because SCI and SSCI are two of the best sources for citation data. We also used the Web of Science, which is a Web-based user interface of ISI’s citation databases. We searched papers using the above queries as where "*" means wildcard. A total of 17,480 papers were retrieved. The data includes all ISI records, i.e. articles, letters, reviews, editorials, meeting abstracts, and so on. Some of these papers may be not relevant to nano risk because we collected data simply by the query described above. Therefore, we focused on the maximum connected component, which currently comprises 6,475 papers and accounts for 37.0%. We ignored the sidetrack papers of nano risk research field.

2.2. Method

The retrieved data were converted into a non-weighted, non-directed network. Subsequently, the network was divided into clusters using the topological clustering method [20, 21]. Traditionally, co-citation has been used to analyze a citation network. However, because co-citation is accompanied by a time lag to create a link, and analysis of intercitation is more relevant in the similarity of pairs of documents than co-citation [22], we used intercitation as a link. The clustering algorithm is based on modularity \(Q\), which is defined as follows [20, 21]:

\[
Q = \sum_{s=1}^{N_m} \left[ \frac{l_s}{l} - \left( \frac{d_s}{2l} \right)^2 \right]
\]

where \(N_m\) is the number of clusters, \(l_s\) is the number of links between nodes in cluster \(s\), \(l\) is the sum of \(l_s\), and \(d_s\) is the sum of the degrees of the nodes in cluster \(s\). In other words, \(Q\) is the fraction of links that fall within clusters, minus the expected value of the same quantity if the links fall at random without regard for the clustered structure. Since a high value of \(Q\) represents a good division, we stopped joining when \(\Delta Q\) became minus. A good partition of a network into clusters means there are many within-cluster links and minimal between-cluster links.

After clustering the network, we characterized each cluster by the titles and abstracts of papers that are frequently cited by the other papers in the same cluster. It does not mean that all papers in the cluster study the same topics as covered in these frequently cited papers. In fact, each paper studies its own topics, and each paper has its own unique focus. However, as a first approach, it is reasonable to
treat these inter-cited papers as a cluster to investigate the brief structure of a research domain and to consider the frequently cited papers in the cluster as representative of the same. The clustered network is visualized by using a large graph layout (LGL) [23], which is based on a spring layout algorithm where links play the role of spring connecting nodes. Thanks to such layout, papers that cite each other and form a group can be located in closer proximity.

3. Results and Discussion

As a result of clustering the network of nano risk citation, we obtained four main clusters: nano risk, drug delivery system (DDS), dye-sensitized solar cell, and carbon nanotube as a sensing material. The major content of the citation network was study on application and minor is nano risk. The reason clusters of application was mingled with nano risk is that terms “exposure” and “injection” were included in the queries. For example, “electron injection to nano-structured TiO$_2$ thin film” was used in dye-sensitized solar cells, and “exposure” was usually used like “exposure of NH$_3$ gas to carbon nanotube sensor”. We focused on and analyzed only the cluster nano risk. Since the cluster nano risk had 1,617 papers and its maximum connected component consists of 1,611 papers, we investigated the structure of the citation network of nano risk for the 1,611 papers. The result was visualized in Figure 1.

![Figure 1. Visualization of citation network in nano risk field.](image)

Nano risk citation network was composed of seven clusters, and each cluster was differently colored in Figure 1. Next, we put the label based on three axes named “Material”, “Hazard” and “Kinetics” (Figure 2) to these seven clusters. Table 1 shows this result and each cluster was characterized as follows:

- **Cluster #0**
  This cluster has many papers with the title of “ultrafine particle” such as diesel-engine-derived particles, particles generated by friction between car tires and pavement, combustion of woods, or generated in room environment. Accordingly, this cluster in general has interest of particles derived in urban life both outdoors and indoors. Its research theme is inclined to exposure assessment or intra-body kinetics of inhaled particles. There’re some epidemiology researches, but researches on hazard or toxicity are rarely seen.
• **Cluster #1**
This cluster has a lot of papers about magnetic nano materials such as Fe$_2$O$_3$ and quantum dots such as CdSe, CdTe, ZnSe etc. Quantum dots are studied for imaging in the living organisms by their fluorescence character, and magnetic nano materials are for imaging mainly brain tumors with the technique of magnetic resonance.

• **Cluster #2**
This cluster consists of papers which examine toxicity of industrial nano materials such as C$_{60}$, CNTs, TiO$_2$, metals. *In vitro* studies were minor until 2004, and *in vivo* experiments were major using some metals or metal oxides nano particles. However, after 2005 studies *in vitro* explodes with initiating and expanding the synthesis of CNTs or C$_{60}$ or other nano materials. The endpoint of *in vitro* experiments is mainly oxidative stress.

• **Cluster #3**
This cluster has papers on CNTs. Hazard study on CNTs has initiated with 2 *in vivo* experiments [24, 25]. Toxicity of CNTs is studied in many endpoints: inflammation, cytotoxicity, ROS, biocompatibility, etc. Intra-body kinetics is hardly studied. The number of *in vitro* studies surpasses *in vivo*.

• **Cluster #4**
This cluster deals with nano particles in air pollution. The aimed point is similar as Cluster #0, but the difference is method: field work for investigating difference between plural cities. Studied particles are diesel particles, sand dusts, fly ashes, etc.

• **Cluster #5**
This cluster has papers written after 2000 and deals with Ag nano particles. Ag nano particles are studied for the existence of anti-bacterial effect.

• **Cluster #6**
This cluster has least paper numbers in the seven clusters, and papers discuss engineering ethic, technology management, and national policy of nano.

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Figure 2. The concept of nano risk assessment.

On the other hand, each number of papers in each cluster year by year was analyzed and shown in Figure 3. From this figure the historical trend of each cluster can be read: Cluster #0 and cluster #1 have conventional themes like atmospheric nanoparticles and nanoparticles used in imaging, with the number of papers in each cluster rising relatively slowly. This is probably because the nano measurement technology has been developed further and quantum dots were emerged around 2002. Clusters #2 and #3 have nearly zero papers until 2001. However, the magnificence of these clusters has been exploding dramatically after 2002, reflecting the increase of R&D for nano materials such as CNTs, C$_{60}$, ultrafine metals or metal oxides and their toxicity assessment. Cluster #4 seems to be the
complement of cluster #0. Cluster #5 gives much attention to Ag nano particles for a good antibiotic property, but the research seems to be in its infancy. Cluster #6 has several papers after 2005, and the reason is papers in this cluster are almost general papers or reviews.

Figure 3. Historical trend of the number of papers in nano risk field.

From the results mentioned above, predicting near future could be partially carried out. By watching Table 1, there’re some blank fields and they may be the next research targets. By watching Figure 3, general trend of each cluster is revealed and extrapolating each line in this figure will tell us the more attracting fields in nano risk researches. More specifically, Figure 1 and explanation for each cluster will give us further information: On cluster #1, researches related to quantum dots are largely cytotoxicity assessment so far (until 2008), and after exploring it will come in vivo toxicity assessment for practical application in society. On cluster #2, seen from Figure 1, there’s a gap between this cluster and clusters #0 or #1. Therefore in recent years, relationship between air pollutant carbon materials and carbon nano materials will probably be clarified, or many kinds of nano materials with quantum dots size will be produced and their toxicity assessment or intra-body kinetics will be investigated. On cluster #3, CNTs in vitro test will be yet major in near future but subsequently in vivo long-span toxicity tests or exposure experiments will be taken, or CNTs with various modifying chemicals will be investigated in the point of bio compatibility.

Table 1. Labelling of each cluster in nano risk.

| No. | Cluster name                           | Material                                      | Hazard                                    | Kinetics                  |
|-----|----------------------------------------|-----------------------------------------------|-------------------------------------------|---------------------------|
| #0  | atmospheric nanoparticles               | diesel exhaust particles, carbon black        | N.D.**                                   | lung deposition           |
|     | (Feb. 2004, n=511)*                    |                                               |                                           |                           |
| #1  | nanoparticles used in imaging          | quantum dot, magnetic nano particle           | N.D.                                     | imaging                   |
|     | (Apr. 2005, n=458)                     |                                               |                                           |                           |
| #2  | toxicity of manufactured nanomaterials | industrial nano material                      | in vitro, oxidative stress                | N.D.                     |
|     | (Mar. 2006, n=363)                     |                                               |                                           |                           |
| #3  | carbon nanotube                        | carbon nanotube                               | cytotoxicity, biocompatibility            | N.D.                     |
|     | (Mar. 2006, n=205)                     |                                               |                                           |                           |
| #4  | field work about atmospheric nanoparticles | diesel exhaust particles, carbon black         | N.D.                                     | urban environmental, field work |
|     | (Jan. 2005, n=34)                      |                                               |                                           |                           |
| #5  | antibiotic nature of Ag nanoparticles  | Ag nanoparticle                               | antibacterial                             | N.D.                     |
|     | (May 2006, n=22)                       |                                               |                                           |                           |
| #6  | engineering ethic and policy about nano| general about nano                            | N.D.                                     | N.D.                     |
|     | (Mar. 2006, n=18)                      |                                               |                                           |                           |

*: (average publicated date, number of papers within cluster), **: not detected
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