The Structure of the Production and Operations Management Field: a Social Network Analysis in Brazil

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Abstract - This study investigates how the construction of scientific knowledge in Production and Operations Management field was structured in Brazil, in the period from 1997 to 2008. By using data from 2,329 papers, networks were constructed in which the nodes are researches, and two researches are connected if they have coauthored a paper. The study assumes that the construction of scientific knowledge is a social process comprehended by a recursive dynamic between social and intellectual dimensions. The results illustrate the dynamics between competition and cooperation in the field along with the construction of scientific knowledge. The findings point out a fragmented network surrounded with clusters, indicating that most part of scientific production and researchers are concentrated. The study shows that when well positioned in the network, the author has higher probability of having higher productivity.

1. INTRODUCTION

The Production and Operations Management (POM) field has experienced substantial changes since the establishment of manufacturing products and processes in the nineteenth century, with occasional crises of identity (SPRAGUE, 2007). In recent decades, these changes have been intensified, with great impact on business as well as on teaching and research activities (GUPTA; VERMA; VICTORINO, 2006).
In this sense, Soteriou (1999) states that POM field was established as one of the key disciplines in most schools of business worldwide. This author highlights some fundamental changes observed in the business environment, such as the increase demand for quality, the emergence of new markets, the internationalization of production and time-based competition.

Thus, the development of POM as a critical area in Management Sciences has motivated researchers to identify and to establish a research agenda, indicating emerging issues and research methodologies (BUFFA, 1980; CHASE, 1980; MILLER; GRAHAM, 1981; AMOAKO-GYAMPAH; MEREDITH, 1989; MEREDITH et al., 1989; SWAMIDASS, 1996; PANNIRSELVAM et al., 1999). Other researchers have made efforts to conduct a review of field production in terms of topics and methods used to investigate the problems identified in the area (FILIPPINI, 1997; PANNIRSELVAM et al., 1999; PRASAD; BABBAR, 2000; ARKADER, 2003; BOYER et al., 2005; PILKINGTON; FITZGERALD, 2006; GUPTA et al., 2006). The latter have highlighted the importance of analyzing publication development and evolution, as well as trends and opportunities for future studies, which largely complements and verifies the research agenda proposed by the former.

In general, as seen in the POM field, the evaluation of scientific fields has the published paper as the unit of analysis. However, scientific knowledge, presented in academic publications, is socially constructed through relationships developed by researchers (KUHN, 1978; POPPER, 1972).

With this premises, this paper attempts to analyze the development of the structure of relationships between researchers in the Brazilian POM field. Besides, this study aims to evaluate the structure of relationships between authors and their roles in the collaboration network, as well as to identify the most prolific researchers and institutions and the indicators of production and productivity of the scientific field.
The paper is divided into six sections, including the introduction. The next will discuss the theoretical background that supports research analysis. The third one, it is presented the methodological procedures chosen to achieve research objectives. After that, the data related to productivity and cooperation is discussed. The fifth section highlights the structure of researchers’ networks. In the final one conclusions and recommendations are made.

2. THEORETICAL BACKGROUND

2.1 THE PRODUCTION AND OPERATIONS MANAGEMENT RESEARCH

The POM research evolution was strongly linked to the business management evolution. Buffa (1980) suggests three steps of development in the POM field from the period after World War II. Throughout the 50s, when it was called the Industrial Management or Factory Management, the study area had a predominantly descriptive characteristic and the main research topics were related to studies of time and movements, the plant layout, production control and description of how production systems operate (BUFFA, 1980). According to Filippini (1997), studies made in this period implicitly assumed that (a) production systems were isolated from the environment and strategically neutral, (b) the prevailing technical resources, and (c) that the ultimate goal was to maximize the productivity of labor.

During the 60’s and 70’s, Operations and Decision Science studies, in general, provided scientific methods that enabled researchers to develop scientific papers similar to the natural sciences, with the insertion of topics such as services management and others that have expanded the possibilities for research in the field (BUFA, 1980). From the analysis of 134 papers published between 1977 and 1979 in major journals, Chase (1980) identified that during the 70’s, researchers have produced little empirical work, which culminated in little application to operation managers. Besides, it was the time of discussion around the
continuity of the POM in the curriculum of schools of business (ANDREWS; JOHNSON, 1982), which generated a need for field legitimacy. In addition, researchers attempted to bring their concerns along with the demands of business, creating a greater focus on empirical work (EBERT, 1990; McCUTCHEON; MEREDITH, 1993).

In this sense, Buffa (1980) proposed a research agenda for operation management with an approach closer to the "practical world", with the purpose of results to be understandable and acceptable to practitioners. The author highlighted the continuation of research on strategic issues such as technology choice, capacity planning, analysis of plant location and issues related to planning and control. The author also stressed issues such as positioning, capacity planning and quality control being important to address issues in services management.

Another research agenda to the field was proposed by Miller and Graham (1981). Unlike Buffa (1980), these authors focused on perception of researchers and professionals. They bring attention to four areas: policies, operations, production control, service management and productivity and technology. To study these issues, Miller and Graham (1981) recommended that researchers should use case studies and other empirical methods in order to expand the methods used by the field that was restricted to the use of simulation and modeling.

The discussions concerned with future directions revitalized the field. Cole (1998) identifies the resurgence of POM in the 80s as one of the main areas in Business Management with the emergence of issues related to quality (Quality Control Circles, Total Quality Management etc.).

The importance of this topic, in view of Slack et al. (2004), helped issues such as lean production, reengineering, supply chain management and e-business being associated with the operations field.
In Brazil, Arkader (2003) analyzed the Brazilian publications in the field. The author found out that the issues studied in the country were associated with the ones published in foreign journals. The issues related to lean production and quality, has matured, began to give way to more strategic and other issues related to supply chain management. It was evaluated also the insertion of Brazilian authors in foreign POM journals and it was found the total of 26 papers, mostly originated from engineering colleges and research institutes, in opposition of business schools.

According to Arkader (2003), there was a methodological problem in Brazilian POM researches as it remained in a pre-paradigmatic state, consisting in a threat to their representation in the Management field. At the same time, it posed a challenge as it consisted also in an opportunity to teachers and researchers from business schools to identify themes, methods and means that could enable it as a discipline in management by its differentiation and legitimacy.

Pannirselvam et al. (1999) finds that the POM field has a low rate of exchange internationally and he explains its causes in three reasons. The first one is related to the pressure for publications in journals of prestige, which is an indicator of the universities status. This one covers the fact that researchers look at what is already legitimized by the field and avoid bearing the risks associated with innovative themes and methodologies.

Another reason given by the authors is that there is some resistance on the part of publishers, and especially by auditors for new issues, especially for new and unknown methods. Editors, sometimes, have difficulty in finding qualified auditors in new methodologies and the reviewers feel uncomfortable with them.

A third one is the high degree of sophistication that new methodologies must show in order to be acceptable. Most of the techniques, despite of new operations, are not new to researchers in other social sciences.
Another problematic aspect is discussed by Slack, Lewis and Bates (2004). Their research was based on the analysis of papers published in JOM and IJOPM during the period from 1990 to 2003. The authors reflects about the existence of two worlds between research and practice in the field of operations, which was a frequent topic since the 80's, as it was described in earlier section.

Slack, Lewis and Bates (2004) conclude their work emphasizing that from the moment that organizations make use of the POM to understand and improve their operational and strategic activities, the researchers of the field of operations will have a more comprehensive and representative environment to development of studies, which may increase their relevance and impact.

This section was dedicated to some aspects related to POM research over the last decades. It was possible to realize that, although some authors have reflected about field production, it was not identified authors discussing social dimension of the field, the purpose of the present research.

2.2 THE SCIENTIFIC SOCIAL DIMENSION AND SOCIAL ANALYSIS NETWORK CONTRIBUTIONS

The importance of scientific activity reflected in the scientific production relies on the fact that it is a formal means of legitimacy for actors in any scientific field (CARVALHO; GOULART; AMANTINO-DE-ANDRADE, 2005).

Bourdieu (1983) considers science field as a social field. The author states that logic would not be different in the scientific field, which is a social field like any other, with its relations of power and monopolies, their struggles and strategies, their interests and profits.

Thus, the concept of field implies the existence of a community of organizations that share common meanings and systems, in which participants interact more frequently among
them than with actors outside the field (SCOTT, 2001). In this work the researchers of the field are seen in a network of social interaction, where they share, compete, share information and resources, where they are joined in schemes of cooperation, organize themselves in various forms for the research and create socially accepted parameters for assessing the recognition or rejection of ideas with pretense of knowledge in the field.

Thus, the analysis of social networks were used to assess the structure of the scientific field of POM in Brazil, from the experience of other fields (BARABASI et al., 2002; GUIMERA et al., 2005, LIU et al., 2005; MOODY, 2004; NEWMAN, 2001a, 2001b, 2001c, 2004; WAGNER; LEYDESDORFF, 2005).

Social networks analysis provides different alternatives to the visibility of knowledge in one area. It is not a formal theory or unit, but a comprehensive strategy of social research (EMIRBAYER; GOODWIN, 1994). With this type of analysis, it is rejected attempts to explain human behavior or the social process only in terms of attributes of the actors (EMIRBAYER; GOODWIN, 1994, SCOTT, 2000; WASSERMAN; FAUST, 1994; WELLMAN, 1988). As Wellman (1983) stated, social behavior is the result of both individual possession of attributes and rules, as the result of their involvement in the structure of social relations.

Thus, the inclusion of concepts and information about the relationship between units of analysis is the main difference between relational and non relational methods of analysis (WASSERMAN, FAUST, 1994). Then, social networks are sets of contacts that connect various actors, in which such contacts may have different types, contents and structural properties.

Wasserman and Faust (1994) conceptualize that there are two different types of variables possible to be used in the analysis: (i) structural variables, which provide information about the links between pairs of actors, and (ii) composition variables, which
consist on the attributes of actors, such as gender, age, and race. According them, the combination of both variables allows researchers to assess not only the relationships but also the effects of author attributes. The combination of variables was headed by White (1966) as CATNETS (categories and networks).

The following section will be dedicated to methodology, as well as the concepts and metrics related to the analysis of social networks.

3. METHODOLOGY

To achieve the stated objectives in this research paper, a descriptive and exploratory study was developed. It was based on documentary research with the use of scientific papers published in major events and Brazilian journals in the period from 1997 to 2008.

The level of research analysis is the researcher network in the POM field and the unit of analysis is each researcher individually. According to Wellman (1988), the level of relationships network is most appropriate for this type of analysis, therefore it is not limited to check intra and inter group relations.

The conferences analyzed were the (i) POM Division on EnANPAD – main Brazilian Management Meeting and (ii) the SIMPOI - Symposium of Management of Production, Logistics and International Operations. In addition, POM papers were extract from the six main Brazilian journals were part of the analysis: (i) RAC, printed and electronic versions [RAC-e]; (ii) RAE, printed and electronic versions [RAE-e]; and (iii) RAUSP, printed and electronic versions [RAUSP-e]). Two POM journals also were analyzed: Management and Production (Federal University of São Carlos - UFSCar) and Journal of Operations and Supply Chain Management (JOSCM).
From the selected papers, it was extracted the units of analysis, i.e. each author who, alone or jointly with other authors, published a scientific paper in the period of time being analyzed. It was analyzed 2,791 authors and 2,329 papers.

3.1 Data Analysis Categories

The data was analyzed using the software Microsoft Excel 2007, UCINET 6.0 (BORGATTA, EVERETT, FREEMAN, 2005), PAJEK 1.10 (BATAGELJ; MRVAR, 2005), and SPSS 15. Microsoft Excel 2007 was used to tabulate the data, to generate dynamic reports measures of productivity and to generate the matrices in the UCINET 6.0. This, together with the PAJEK 1.10, were used to calculate the metrics of social networks of researchers and to draw them. Finally, the SPSS 15.0 was used to test the relationship between the centrality of authors and their scientific production, by means of simple linear regression.

Density

Density is a parameter of the network, which expresses the ratio number of links in one group divided by the total number of possible links between the actors that comprise the network (KNOKE; KUKLINSKI, 1982). This structural indicator varies in an interval [0,1], which the closer to 0 is less connected to the network, the closer to 1, the closest is to be fully connected network.

This is an important parameter to assess the connectivity of a network. In environments of high density of relationships, its content becomes increasingly redundant (KOGUT; WALKER, 2001). Networks with low density have weak-ties. Thus, relationships established outside of the circle (i.e. weak-ties) allow access to other sources of information and resources, which can lead to new forms of knowledge.
Kuhn (1978) states that the cohesion between scientists may lead them to see new paradigms such as inconsistencies, particularly when they already have an old tradition in research, and they need to seek interaction with other researchers outside the group.

**Components**

A major effort in social networks is to find the various sub-groups together in the network can be divided (SCOTT, 2000). Component is the simplest of all concepts of sub-networks. Components are fully connected sub-networks (WASSERMAN, FAUST, 1994). In a component, all nodes are connected by links, but no link is made with an actor outside of the component (SCOTT, 2000).

**Centrality**

The centrality is configured as a property that measures how central is an actor in a network (SCOTT, 2000; WASSERMAN, FAUST, 1994). In analysis of social networks is common to identify the most central actors, as relates to this position on the importance of the network. To size the centrality of the actors, there are different measures, and two more used: Degree Centrality and Centrality (SCOTT, 2000; WASSERMAN, FAUST, 1994).

Degree Centrality: is the number of ties that an actor has with other actors in a network (WASSERMAN, FAUST, 1994). According to Scott (2000) as the degree of centrality takes into account only the adjacent relationships, this only shows the local centrality of actors.

Betweenness Centrality: the interaction between non-adjacent actors might depend on other actors, which may potentially have some control over the interactions between two actors not adjacent. In this sense, according to Freeman (1979) and Wasserman and Faust (1994), an actor is an agent if it binds several other actors that do not connect directly.
Structure of Social Network

This is in the relationship between social entities, their characteristics and implications for those involved (WASSERMAN, FAUST, 1994). This category was used by the analysis of the structural elements of the network (size, density and components) and the positions of researchers in the network (Degree and Betweenness centralities).

Scientific Production

The scientific production is the expression of scientific knowledge, in the form of papers, built from the practices of researchers in search of a scientific field. In this paper used the descriptive analysis of indicators of scientific output (papers published; Papers per Author, Author per Paper; Papers per Attribute; Papers per Institutions).

Dynamic Relationship between Researchers

This dynamic is related to the development of networks of relationships in a given period of time represented in the form of changes in the structure of relationships (MOODY, 2004; WASSERMAN, FAUST, 1994). In this study, this concept was based on longitudinal assessment of the structural indicators (size, density and components) and positioning of the researchers in the network (Degree and Betweenness centralities).

3.2 LIMITATIONS

As in any scientific work, it is possible to highlight some limitations. The first one is related to the type of relationship chosen for analysis because researchers do not cooperate only through publication of scientific papers. There are also informal relationships that can be analyzed. Another limitation is related to the delimitation of the research. The journals and
events studied don not consist on the total possible means of publication. However, they are the Brazilian main ones, and that fact makes the cut representative.

4. PRODUCTIVITY AND COOPERATION INTO BRAZILIAN POM FIELD

This section discusses the development of indicators of production, productivity and cooperation in the Brazilian POM field. The data shows a growth in the number of publications during the twelve years analyzed, as shown in Figure 1. In 1997, 50 papers were published in the field, and in 2008, such number reached 300. Despite the growth of paper number in the journals, the exponential growth observed in the field was based on papers published in conferences. Also based on Figure 1, it was possible to verify a growth on field production not only in terms of published papers number, but also in the volume of researchers and authorships. It was observed that starting in 1999, there were a detachment between the volume of authorship and the volume of writers that produced in the field, impacting the increase of researcher’s productivity, what indicated a growth on the average number of authors.

![Figure 1 - Number of authorship, articles, and authors of the field of operations in Brazil](image)

Source: research results

The remarkable growth of the field has important contributions of some researchers who attempted, in a consistent way, disclose the results of their efforts in academic events and
periodic analyzed. Then, it is identified the most prolific authors in the period analyzed (Table 1). It was observed that most of them have most of their production in published events.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Articles in conferences</th>
<th>Articles in journals</th>
<th>Total of articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Csillag, J.M.</td>
<td>33</td>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>Moorii, R.G.</td>
<td>28</td>
<td>3</td>
<td>31</td>
</tr>
<tr>
<td>Serio, L.C.D.</td>
<td>26</td>
<td>2</td>
<td>28</td>
</tr>
<tr>
<td>Pereira, S.C.F.</td>
<td>20</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>Barbieri, J.C.</td>
<td>17</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>Paiva, E.L.</td>
<td>13</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>Erdmann, R.H.</td>
<td>18</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>Pires, S.R.I</td>
<td>10</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>Brito, E.P.Z.</td>
<td>17</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>Graeml, A.R.</td>
<td>16</td>
<td>0</td>
<td>16</td>
</tr>
</tbody>
</table>

Source: research results

The institutions that most contributed to the academic production in POM have also been identified (Table 2). It was found that the FGV-EAESP has participated in 10% of the entire production of the field, although it is based heavily on events. The UFSCar, which also has a prominent role, has a more balanced production between events and journals.

<table>
<thead>
<tr>
<th>Institutions</th>
<th>Articles in conferences</th>
<th>Articles in journals</th>
<th>Total of articles</th>
<th>Percentage of authorship</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGV-EAESP</td>
<td>505</td>
<td>38</td>
<td>543</td>
<td>10,33%</td>
</tr>
<tr>
<td>UFSCar</td>
<td>164</td>
<td>149</td>
<td>313</td>
<td>5,96%</td>
</tr>
<tr>
<td>MACKENZIE</td>
<td>249</td>
<td>12</td>
<td>261</td>
<td>4,97%</td>
</tr>
<tr>
<td>POLI/USP</td>
<td>123</td>
<td>108</td>
<td>231</td>
<td>4,40%</td>
</tr>
<tr>
<td>UFRGS</td>
<td>165</td>
<td>45</td>
<td>210</td>
<td>4,00%</td>
</tr>
<tr>
<td>UFSC</td>
<td>188</td>
<td>8</td>
<td>196</td>
<td>3,73%</td>
</tr>
<tr>
<td>UFRJ</td>
<td>146</td>
<td>44</td>
<td>190</td>
<td>3,62%</td>
</tr>
<tr>
<td>USP/SCarlos</td>
<td>88</td>
<td>72</td>
<td>160</td>
<td>3,05%</td>
</tr>
<tr>
<td>FEA/USP</td>
<td>109</td>
<td>34</td>
<td>143</td>
<td>2,72%</td>
</tr>
<tr>
<td>UFMG</td>
<td>89</td>
<td>13</td>
<td>102</td>
<td>1,94%</td>
</tr>
<tr>
<td>Total</td>
<td>1826</td>
<td>523</td>
<td>2349</td>
<td>44,71%</td>
</tr>
</tbody>
</table>

Source: research results

The institutions listed in Table 2, which represent 2% of the total amount, are responsible for almost 45% of published papers, indicating the stratification of the production field.
The POM field in Brazil grew considerably from 1997 to 2008. Table 3 shows the evolution of the number of papers, authors and authorship. These measures were used to calculate indicators of authors’ productivity and cooperation in the field.

<table>
<thead>
<tr>
<th>Year</th>
<th>Articles</th>
<th>Authors</th>
<th>Authorship</th>
<th>Cooperation</th>
<th>Total Productivity</th>
<th>Marginal Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>58</td>
<td>94</td>
<td>106</td>
<td>1,828</td>
<td>1,128</td>
<td>0,617</td>
</tr>
<tr>
<td>1998</td>
<td>83</td>
<td>125</td>
<td>141</td>
<td>1,699</td>
<td>1,128</td>
<td>0,664</td>
</tr>
<tr>
<td>1999</td>
<td>80</td>
<td>138</td>
<td>157</td>
<td>1,963</td>
<td>1,138</td>
<td>0,580</td>
</tr>
<tr>
<td>2000</td>
<td>135</td>
<td>223</td>
<td>263</td>
<td>1,948</td>
<td>1,179</td>
<td>0,605</td>
</tr>
<tr>
<td>2001</td>
<td>198</td>
<td>381</td>
<td>460</td>
<td>2,323</td>
<td>1,207</td>
<td>0,520</td>
</tr>
<tr>
<td>2002</td>
<td>200</td>
<td>339</td>
<td>416</td>
<td>2,080</td>
<td>1,227</td>
<td>0,590</td>
</tr>
<tr>
<td>2003</td>
<td>223</td>
<td>388</td>
<td>486</td>
<td>2,179</td>
<td>1,253</td>
<td>0,575</td>
</tr>
<tr>
<td>2004</td>
<td>213</td>
<td>400</td>
<td>484</td>
<td>2,272</td>
<td>1,210</td>
<td>0,533</td>
</tr>
<tr>
<td>2005</td>
<td>264</td>
<td>503</td>
<td>608</td>
<td>2,303</td>
<td>1,209</td>
<td>0,525</td>
</tr>
<tr>
<td>2006</td>
<td>310</td>
<td>608</td>
<td>744</td>
<td>2,400</td>
<td>1,224</td>
<td>0,510</td>
</tr>
<tr>
<td>2007</td>
<td>264</td>
<td>530</td>
<td>637</td>
<td>2,413</td>
<td>1,202</td>
<td>0,498</td>
</tr>
<tr>
<td>2008</td>
<td>301</td>
<td>583</td>
<td>752</td>
<td>2,498</td>
<td>1,290</td>
<td>0,516</td>
</tr>
</tbody>
</table>

Source: research results. Note: Cooperation: authorship/article; Total Productivity: authorship/author; Marginal Productivity: articles/author.

The cooperation, which indicates the average number of authors per paper in each year, increased 36% from 1997 to 2008. In one hand, the total productivity, which reflects the average number of authorship for each author, also grew in the same period. In other hand, the marginal productivity, which indicates the average contribution of each paper published by author decreased. Thus, although the number of papers published in the field has grown considerably, the average productivity of each author individually decreased in the period analyzed.

The results presented in this topic shows how POM field has evolved over the period from 1997 to 2008, in Brazil, as the total amount of published papers and authors working in the field has grown considerably, resulting in a growth of the field. There are more authors per paper, which indicates the tendency of researchers to have greater cooperation in the production of papers. In order to deep the analysis of field evolution, it seems interesting to get to know separately field publications and how they followed this development.
5. RESEARCHERS COOPERATION NETWORK IN BRAZILIAN POM FIELD

This section displays the results of longitudinal study of relationships between researchers of POM field in Brazil. Thus, we tried to investigate how they are organized to cooperate in the scientific production in the period 1997 to 2008.

The analysis was based on 2,329 papers and 2,791 authors in the period analyzed. Figure 2 presents a network of researchers throughout the analysis period (1997-2008). Different colors represent different components, which is a sub-network where the nodes are interconnected (DE NOOYI; MRVAR; BATAGELJ, 2005; WASSERMAN, FAUST, 1994). The nodes in black are the main component, the largest fully interconnected network. By identifying a large number of colors, there is the existence of a large number of authors that non-cooperation directly, or indirectly, among them.

Figure 2 - Structure of the Scientific Network Collaboration in Brazilian POM field (1997-2008)
Source: research results. Note: the colors of nodes indicate the components that integrate the entire network. Components are sub-networks with all nodes interconnected. The black nodes represent the authors into the main component - the largest fully interconnected network.
The existence of several groups of authors indicates fragmentation of the field. When in collaborative networks, researchers have greater probability of sharing ideas and one can influence the scientific activity of the other (MOODY, 2004).

Table 4 presents the descriptive statistics of the relationships between authors and their evolution in the periods analyzed. The columns for each analysis period (1997 to 2000, from 2001 to 2004, from 2005 to 2008) present data from the network of authors who published articles in their respective years. The last column shows the network data of relationships of authors who collaborated on at least one paper in the period studied.

<table>
<thead>
<tr>
<th>Table 4 - Descriptive statistics of the Brazilian POM field network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period 1</td>
</tr>
<tr>
<td>Articles</td>
</tr>
<tr>
<td>Author</td>
</tr>
<tr>
<td>Authorship</td>
</tr>
<tr>
<td>Average number of ties per author</td>
</tr>
<tr>
<td>Density</td>
</tr>
<tr>
<td>Isolated Authors</td>
</tr>
<tr>
<td>Number of Components</td>
</tr>
<tr>
<td>Number of authors in main component</td>
</tr>
</tbody>
</table>

Source: research results.

The number of articles grew 3 times from the first to the last period being the latter responsible for almost half volume of the total papers published over the twelve years analyzed. The number of authors grew up in larger scale than the volume of articles, which indicates more authors per article and, consequently, greater relationship between the authors. This relationship can be seen in the average number of ties per author, which increased considerably, showing a structure of cooperation. Between 2001 and 2004, it was identified 2,534 ties, a number 3.5 times higher than in the first period. Between 2005 and 2008, it was identified 3,922 ties, a number 1.5 times higher than the previous period. De Nooyi, Mrvar and Batagelj (2005) propose that when the network decreases its growth rhythm, there is indication of maturity of its structure. Analyzing the whole period, each author cooperated, on average, with 2,448 researches.
Also based on Table 4, the number of authors who published isolated felt and represented 6% of authors. The density of relationships in the global network was low in all periods analyzed. This measure indicates the percentage of possible ties in the network that are effectively achieved. In total, the network measure was 0.09% and it felt from first to last period with the network’s growth. The result of the operations network density as slightly lower than the one found in the Brazilian Strategy and Organizational Studies’ network, as identified by Rossoni (2006), which was 0.11%.

The components can be used to evaluate patterns of local cooperation. Over the years, the number of components increased significantly, in a smaller scale than the number of authors who work in the field. From 1997 to 2000, it was identified 121 components, 246 from 2001 to 2004 and 318 from 2005 to 2008. In other words, the number of researchers in a completely interconnected network increased, indicating that most local people were grouped with the advance of periods. In the twelve-year network, the main component consists of 1,245 authors, equivalent to 44.60% of the authors of the field. According to Newman (2004), in the biology, physics and mathematics fields, in an international context, the principal component represents 82% to 92%; in Computer Science field, this proportion was 57.2% (NEWMAN, 2001c). Thus, the main component of the Brazilian POM field is lower than the ones found in other international fields. In Brazil, Rossoni (2006) found out that the main component of the Strategy and Organizational Studies field was 37.9%; in Information Technology Management, its represent only 12% of researchers in the field (ROSSONI; HOCAYEN - DA-SILVA, 2008). Therefore, although the main component of POM network in Brazil is shorter than the patterns founded internationally, it is larger than others Scientific Management fields studied in Brazil.

This paper also identified the most central authors in the Brazilian POM network. The centrality was discussed in terms of the number adjacent ties per researcher (Degree
Centrality), as well as the ability of the researcher to be well positioned in the network, intermediating relations (Betweenness Centrality).

In studies of scientific fields, the identification of authors with greater ability to construct relationships can bring important conclusions about the field’s dynamics. This occurs because such researchers can be seen as agents with capacity to produce some effect on the structure of the field. While an agent cannot handle the entire field, he can cause important changes when his production is accepted by their peers.

In this sense, the first measure examined is the Degree Centrality of the authors, which can be understood as the number of direct ties (i.e. first-level) that a researcher has in the network (WASSERMAN; FAUST, 1994). Table 5 presents the authors with the greatest Degree Centrality in the period.

Another indicator of centrality measured was the Betweenness Centrality. This measure assesses the ability of the author to participate in different groups in the same network, controlling the information flow between members. Table 5 also shows the authors with greater capacity in the Brazilian POM Field.

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Degree Centrality</th>
<th>Researcher</th>
<th>Betweenness Centrality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moorí, R.G.</td>
<td>29</td>
<td>Gonçalves, M.A.</td>
<td>251.965</td>
</tr>
<tr>
<td>Serio, L.C.D.</td>
<td>29</td>
<td>Sacomano-Neto, M.</td>
<td>207.105</td>
</tr>
<tr>
<td>Erdmann, R.H.</td>
<td>24</td>
<td>Martins, R.S.</td>
<td>196.794</td>
</tr>
<tr>
<td>Csillag, J.M.</td>
<td>23</td>
<td>Moorí, R.G.</td>
<td>191.962</td>
</tr>
<tr>
<td>Carpinetti, L.C.R.</td>
<td>21</td>
<td>Pereira, S.C.F.</td>
<td>190.760</td>
</tr>
<tr>
<td>Paiva, E.L.</td>
<td>21</td>
<td>Pires, S.R.I.</td>
<td>179.976</td>
</tr>
<tr>
<td>Martins, R.S.</td>
<td>20</td>
<td>Sacomano, J.B.</td>
<td>170.644</td>
</tr>
<tr>
<td>Morabito, R.</td>
<td>17</td>
<td>Csillag, J.M.</td>
<td>167.846</td>
</tr>
<tr>
<td>Pires, S.R.I.</td>
<td>17</td>
<td>Leite, R.S.</td>
<td>160.699</td>
</tr>
</tbody>
</table>

Source: research results.

Some authors combine high Degree and Betweenness Centrality of intermediation. Others present a great ability to intermediate relationships in the network, but do not have much amount of direct ties.
From the definition of centralities measures in the collaboration network, it seems interesting to identify the sensitivity of the authorship volume of $i$-th author ($Aut_i$) to his position in the network. In other words, it was estimated the relation of authors’ centrality and his scientific production. The models and results can be seen in equations 01 to 04.

\[ Aut_i = \beta_0 + \beta_1 \times Degree_i + \xi_i \]  
\[ Aut_i = 1,986 \times 10^{-2} + 0,777 \times Degree_i + \xi_i \]  
\[ Aut_i = \gamma_0 + \gamma_1 \times Betweenness_i + \xi_i \]  
\[ Aut_i = 1,638 + 8,945 \times 10^{-5} \times Betweenness_i + \xi_i \]

These relationships were tested by ordinary least squares (OLS) linear regression, with 99% confidence level. The results showed positive betas, indicating that the more a researcher is central in the network, increase his probability to produce a paper.

Beta standardized was observed in order to compare both centralities. The Degree Centrality has 0.813 a standardized Beta and 0.603 for Betweenness Centrality. This result suggests that it seems more contributive to prioritize a large number of first-level ties with other researchers (Degree Centrality) than to establish a position that gives the author ability to manage knowledge and information flow (Betweennes Centrality).

6. CONCLUSIONS AND RECOMMENDATIONS

With the premises that scientific knowledge is socially constructed (Kuhn, 1978; Popper, 1972) and that researches networks are formed when preparing scientific papers, this paper analyzed the development of the structure of relationships between researchers in the Brazilian POM field. Besides, this study evaluated the structure of relationships between authors, their roles in the collaboration network, and to identify the most prolific researchers and institutions, as well as the indicators of production and productivity of the scientific field.

Over the period analyzed, it was observed an exponential growth in the number of articles published in the field, and this growth was based on papers published in conferences.
Thus, more authors are publishing more papers. Most publications have a co-authorship structure, indicating growth of cooperation in the field. This expansion seems to have direct relation with the growth of post-graduate programs in the country.

The scientific production of the field was very stratified, concentrated in few researchers and institutions. The identification of these institutions and researchers may increase the interaction between them. This type of information may be valuable to students who are selecting institutions to study in POM area. Additionally, the identification of institutions, researchers and research groups can serve as guidance for publishers, colleges and companies in the search for institutions and scholars for the development of projects in the area are in teaching, research or extension.

The researchers network has grown exponentially over the period analyzed. In the period from 1997 to 2000, there were little more than 400 researchers working in the field. That figures grew to around 1,700 from 2005 to 2008. The average number of ties of co-authors of these researchers also rose, indicating that the authors tend to relate more now than in the past. However, the density decreased with network growth, a normal behavior according to Burt (1992).

Otherwise, authors who have more impact on the network were identified, based on its centrality. In the context of Brazilian POM field, it seems more interesting to establish a greater number of ties than establish relationships with researchers who already have many ties.

Thus, this study identified relationships between the dynamics of networks of researchers and scientific production in Brazilian POM field. Naturally, the subject is not exhausted and, thus, recommendations for future studies can be made. Other forms of relationships between researchers can be studied, in a qualitative way, seeking to understand how collaboration network are constructed. In addition, the replication of this paper in the
international context could bring significant contributions to understanding the dynamics of the POM field.

7. REFERENCES


BATAGELJ, Vladimir; MRVAR, Andrej. *PAJEK - Program for Analysis and Visualization of Large Networks*. Ljubljana, Slovenia: University of Ljubljana, 2005.


