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Productivity and Scientific Cooperation: an Analysis of Operations Management Field

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Abstract - This paper is based on the assumption that the construction of scientific knowledge is a social process characterized by the recursive dynamic between the social and intellectual dimensions. We investigated how the relationship between the researchers' network and scientific production in Operations Management field was structured internationally, in the 1997-2008 period. The study is based on documentary research of papers published in the top three relevant operations journals identified by Soteriou et al. (1999) and Barman et al. (2001): POM, JOM and IJOPM. For this purpose, we analyzed social networks and used bibliometric indicators in order to map the cooperation relationships between researchers and institutions, based on co-authorship. The results allow the identification of most prolific authors and institutions. The findings also point out a fragmented network surrounding clusters of scientific collaboration that concentrates the most part of the scientific production and researchers in the field.

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 researching activities (GUPTA; VERMA; VICTORINO, 2006).

Furthermore, 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 the 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 production field 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 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. SCIENTIFIC COOPERATION AND SOCIAL NETWORK ANALYSIS

Scientific cooperation is comprehended as a complex social phenomenon (GLANZEL; SCHUBERT, 2004) that aims to enhance the scientific production of researchers as a means of legitimating in one scientific field (CARVALHO; GOULART; AMANTINO-DE-ANDRADE, 2005). The search for cooperation is often related to a strategy of accessing resources in order to enable research - resources such as economic (direct or indirect) and the ones related to the knowledge itself (GLANZEL; SCHUBERT, 2004).

According to Acedo, Barroso, Casanueva and Galan (2006) (2006), during the first half of the twentieth century, scientific papers written by more than one author were relatively rare and therefore the research was consisted mainly of work done by individuals lonely, who published papers without the use of a network of collaboration. Furthermore, the authors argue that the trend of co-authorship came from the natural sciences and today it still continues to be more connected to it. However, there has been an increase also in the social sciences.

As a result of this increasing trend of work done on co-authorship, Acedo et al. (2006) explain that there is an interest among academic researchers in the phenomenon of collaboration between scientists, which is illustrated by the work by Barabási et al. (2002), Moody (2004) and Newman (2001). With regard to scientific collaboration, Glanzel and Schubert (2004) believe that it is a complex social phenomenon in the research, with focus of study in a systematic way since 1960.

The analysis of co-authorship from published articles is one kind of scientific collaboration analysis. Co-authorship is the most formal manifestation of intellectual collaboration in scientific research and it involves the participation of two or more authors in the production of a research study. Among the possible influences to the increase of scientific publications with co-authors are: the maximization of economic resources (whether direct or indirect) that can lead to research, and greater access to financial resources and equipment, as well as intra-scientific factors (especially from changing patterns in the communication and increased mobility of scientists), allowing greater access to expertise, improving productivity and reducing the isolation of knowledge (ACEDO et al. 2006; Newman, 2004).

According to these authors, studies on co-authorship had two approaches: (1) to analyze the reasons why authors collaborate to write a paper, and the consequences of such collaboration while (2) to analyze the social network of researchers that is created through the collaboration. In this sense, the study of collaborative network of articles gives an understanding of some of the characteristics of a particular discipline and social groups that exist in a scientific field. Recent studies have shown the potential of Social Network Analysis in the discovery of this line of research. This method of analysis allows the examination of relations of cooperation and conduct in publishing a sociological perspective. Moreover, it can reveal interesting features about the academic communities. (BARABÁSI et al., 2002; NEWMAN, 2001; MOODY, 2004)

Newman (2004) emphasizes that in the network of co-authorship, the nodes represent authors, and two or more authors are connected by a line if they are coauthors in one or more papers. In this type of analysis, the networks can reveal much about the social structure of the academic structure of knowledge. It has been since the advent of widespread availability of online bibliographies that construction of complete networks

of a whole scientific field was possible. Thus, as early as 2000, several researchers started to build large scale networks and to represent research in mathematics, biology, physics, computer science and neuroscience.

Besides the analysis of co-authorship has been used at different levels (individuals, institutions, sectors and countries), another variation found in previous studies was the analysis of longitudinal data. Barabási et al. (2002) justify the need for a longitudinal study due to the fact that networks of co-authors constantly expand by the increase of new actors and associations between authors (co-authorship). Thus, the properties of the topology of these networks are determined by dynamic processes and growth and to understand this topology is necessary to understand the dynamic process that determines their evolution.

Recent studies have shown the potential of social network analysis in the investigation of scientific collaboration (eg BARABÁSI et al., 2002; Newman, 2001). According to Moody (2004), the social network analysis allows the examination of relations of cooperation in a sociological perspective. The author points out that recent work in the sociology of knowledge suggest that the set of ideas that a person believes to be true is largely a function of the group of people in which he or she interacts, as well as the references recognized by the group, what has been shown in groups small (see Martin, 2002) and is consistent with the literature of social production of scientific knowledge.

In the present study, the researchers in the field are seen in a network of social interaction, where they share and compete information and resources, they are associated with the cooperation schemes organized in varied ways to research and create socially accepted parameters for evaluation, recognition or rejection of ideas with a pretense of knowledge in the field.

3. METHODOLOGY

To achieve the stated objectives, a descriptive and exploratory study was developed. It was based on documentary research with the use of scientific papers published in the top three most relevant operations journals (according to BARMAN *et al.*, 2001) in the period from 1997 to 2008.

The journals analyzed were (i) IJOPM – International Journal of Production and Operations Management (ii) JOM – Journal of Operations Management and (iii) POM – Production and Operations Management.

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.

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.

3.1 Data Analysis Categories

The data was analyzed using the software Microsoft Excel 2007, UCINET 6.0 (BORGATTA, EVERETT, FREEMAN, 2005) and PAJEK 1.10 (BATAGELJ; MRVAR, 2005). 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.

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

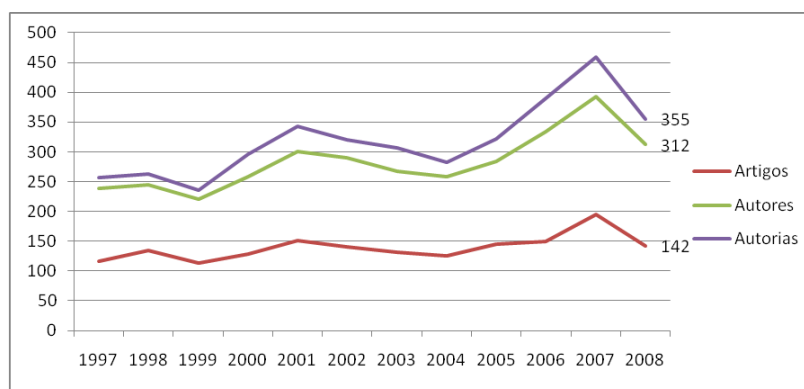
As in any scientific work, it is possible to highlight some limitations. The first one is related to the type of relationship chosen for analysis because researchers do not cooperate only through publication of scientific papers. There are also informal relationships that can be analyzed. Another limitation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

4. PRODUCTIVITY AND COOPERATION IN THE OPERATIONS FIELD

This section discusses the evolution of indicators of production, productivity and cooperation of POM field. The data indicate that the number of publications in the field

of operations grew in the twelve years analyzed, as shown in Figure 1. The average was 140 articles per year, with a peak in 2007 of 195 papers.

Figure 1 - Number of authorship, articles and authors of the POM field (JOM, POM and IJOPM)



Source: Research results

The POM field grew in terms of number of papers published, volume of researchers who produced them and volume of authorship. The growth of the field had an important contribution of some researchers who have sought consistently to disseminate the results of their efforts on events and academic journals analyzed. Thus, we identify the authors with the highest number of authorships in papers published in the period analyzed (Table 02) and it is observed that the most prolific authors went through more than university.

Table 02 - Number of papers published by the most prolific authors in the POM field (13 or more items)

Researcher	Institution(s)	1997-2000	2001-2004	2005-2008	Total
Schroeder, R. G.	Monash Univ.	3	14	8	25
Roth, A.	Clemson Univ.; Univ. of North Carolina	2	8	8	18

Voss, C.	London Business School	2	6	9	17
Boyer, K. K.	Michigan State Univ.; DePaul Univ.	4	4	8	16
Narasimhan, R.	Michigan State Univ.	3	6	6	15
Rungtusanatham, M. J.	Arizona State Univ.; Univ. of Minnesota; Univ. of Wisconsin	1	7	7	15
Droge, C.	Michigan State Univ. Arizona State Univ.; Michigan State Univ.;	5	6	2	13
Handfield, R. B.	North Carolina State Univ.;	7	1	5	13
Klassen, R. D.	Univ. of Manchester; Univ. of Victoria Univ. of Western Ontario	2	4	7	13
Neely, A.	Cranfield Univ.;	5	5	3	13
Vonderembse, M. A.	Univ. of Cambridge Rochester Inst. of Tech.;	4	5	4	13
	Univ. of Toledo				

Source: Research Results

The institutions that contribute most to the academic research in operations management were also identified. It was found the most prolific institutions in North America and Europe, with a predominance of USA and UK. The institutions listed in Table 3 represent 04% of the institutions that produced in the field of operations for the quarter and accounting for nearly 27% of published articles, indicating the stratification of field production.

Table 04 - Number of authorships of the most prolific institutions in the POM field (1997-2008)

Institutions	Country	IJOPM	JOM	POM	Total	% of Total Amount of Authorships
Michigan State Univ.	USA	23	95	10	128	3,34%
Cranfield Univ.	UK	80	5	-	85	2,22%
Univ. of Minnesota	USA	7	57	17	81	2,12%
Univ. of Texas	USA	11	17	41	69	1,80%

Arizona State Univ.	USA	21	40	7	68	1,78%
Univ. of Cambridge	UK	54	7	1	62	1,62%
Univ. of Bath	UK	42	5	3	50	1,31%
Politecnico di Milano	Italy	40	2	-	42	1,10%
Univ. of North Carolina	USA	14	15	13	42	1,10%
Indiana Univ.	USA	10	21	9	40	1,04%
London Business School	UK	18	15	5	38	0,99%
Georgia Inst. of Tech.	USA	2	16	19	37	0,97%
Ohio State Univ.	USA	11	21	5	37	0,97%
Hong Kong Polytechnic Univ.	China	12	10	14	36	0,94%
Univ. of Warwick	UK	32	2	-	34	0,89%
Univ. of Western Ontario	Canada	6	21	7	34	0,89%
Univ. of Toledo	USA	5	27	-	32	0,84%
Univ. of Wisconsin	USA	12	11	5	28	0,73%
Monash Univ.	Australia	26	1	-	27	0,71%
Pennsylvania State Univ.	USA	7	7	13	27	0,71%
Univ. of Strathclyde	UK	27	-	-	27	0,71%

Source: Research Results

The concentration of production operations in terms of countries is more evident when we look at Table 05. Only U.S. institutions account for 52% of the authorship of the field, while the United Kingdom is 18%. That is, the institutions of these two countries together have 70% of the authorship of articles of Operations. We can see that the non-American institutions have concentrated their production IJOPM.

Table 05 - Number of authorship in papers published by countries in each journal of Operations (1997-2008)

Country	IJOPM	JOM	POM	Total	% of Total Amount of Authorships
USA	464	999	529	1992	52,02%
UK	627	61	18	706	18,44%
Canada	44	66	26	136	3,55%
China	53	39	29	121	3,16%
Italy	100	14	-	114	2,98%
Netherlands	69	12	16	97	2,53%
Australia	64	22	-	86	2,25%

Spain	62	13	4	79	2,06%
Sweden	49	4	3	56	1,46%
Brazil	29	3	3	35	0,91%

Source: Research Results

5. OPERATIONS MANAGEMENT RESEARCHERS NETWORK

This section sets out the results of a longitudinal study of relationships among researchers in the POM field. We analyzed the evolution of network structural measures as well as measures related to relationships of authors in the field from 1997 to 2008. Figure 02 represents the network of researchers throughout the analysis period (1997-2008). Each color represents a component, which is a sub-network where the nodes are connected together (De Nooy; MRVAR; Batagelj, 2005; Wasserman, Faust, 1994). The nodes in red represent the major component, which is the largest fully integrated network. Due to the identification of a large number of colors, it is possible to conclude that there is a large number of authors who do not cooperate directly to others.

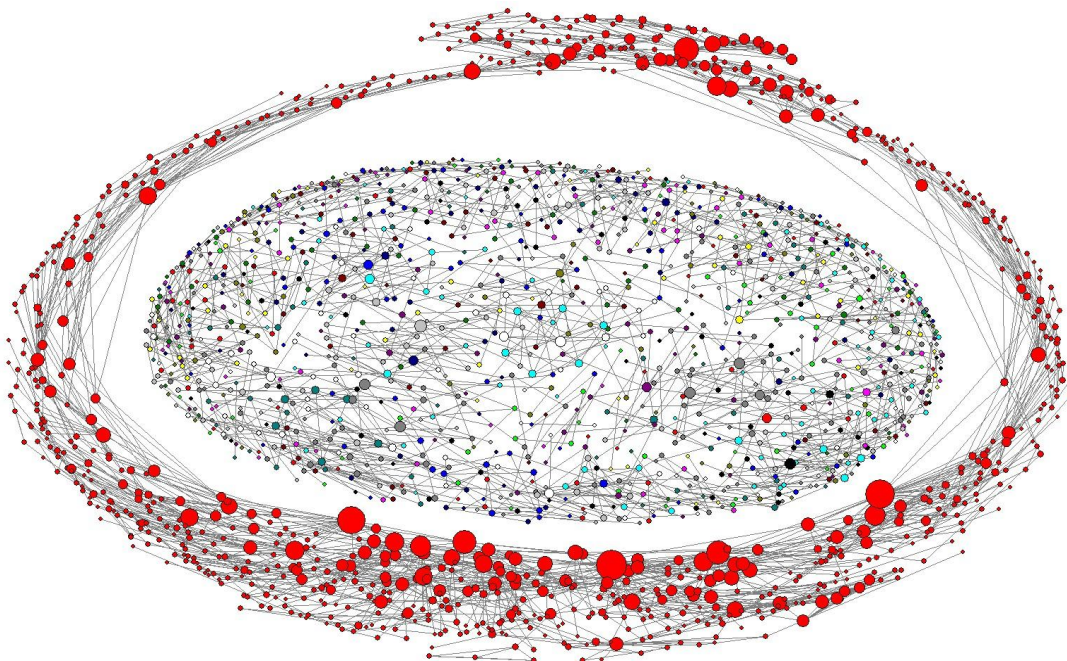


Figure 02 - Structure of the International Network of co-authored by researchers of operations (1997-2008)

Source: Research Results. Note: the colors of nodes indicate the components of the entire network. Components are sub-networks where nodes are interconnected. The nodes in red on the periphery represent the authors belonging to the main component - the largest fully integrated network.

The existence of several groups of authors indicates fragmentation of the field. In collaborative networks, researchers can more easily share ideas, so each one can influence the scientific activities of others (Moody, 2004). Table 07 presents the descriptive statistics of relationships between authors and their evolution in the periods analyzed. The columns for each period (1997-2000, 2001-2004, 2005-2008) present data from the network of authors who published papers in the respective years. The last column does not represent a simple sum of the periods, but recalculates the measures of the network of the entire period.

Table 07 - Descriptive Statistics of Relationship

	Period 1	Period 2	Period 3	Total
	1997-2000	2001-2004	2005-2008	1997-2008
# Authors	791	903	1065	2198
# Ties	1.498	1.864	2.494	5.484
Average number of ties per author	1,894	2,064	2,342	2,495
Density	0,37%	0,34%	0,31%	0,16%
Isolated Authors	83	58	48	118
# Components	212	228	229	399
# Authors in the Main Component	57 (7,2%)	67 (7,4%)	180 (16,9%)	799 (36,4%)

Source: Research Results

The growth in the average number of ties per author points out the development of a framework of collaboration, as well as an increase in the number of relationships between authors. A tie is defined as the number of authors with each author worked (ie co-authored), and not the number of times one author have cooperated (DE Nooyi, MRVAR and Batagelj, 2005). According to these authors, when there is a decrease in the rate of growth of the network of relationships throughout the periods, it is not an

indication of the maturity structure of the network. For any period, each author worked an average of 2.495 authors to produce papers.

Also based on Table 07, it can be observed that the proportion of authors who published isolated fell and it represents 5% of total authors. Furthermore, the indicator of density of relationships in the global network was low in all periods analyzed. Such measure indicates the percentage of possible ties in the network that are actually made. In total, the indicator was 0.16%, which dropped from the first to the last.

Another way to assess the patterns of local cooperation is to analyze the formation of components. It can be noted an increase of the network, and also an increase in the number of components, in a smaller scale if compared to the number of authors who worked in the field.

From 1997 to 2000 were formed components 212, 228 from 2001 to 2004 and 229 from 2005 to 2008. Thus, the little change in the second period if compared to the third indicates a maturing of the network structure.

The size of the identified components indicates that as the network grows, the main component became more representative. In total period network, the main component was composed of 799 authors, which is equivalent to 36.4% of the authors of the field. According to Newman (2004), in biology, physics and mathematics in an international context, the main component represents 82% to 92% for Computer Science, the proportion was 57.2% (Newman, 2001). Thus, the main component of the field of operations is smaller than those found in other international fields.

Researchers Centrality

The centrality was discussed in terms of the number of bonds of the first level set by a researcher (degree centrality) as well as the ability of the researcher to position

itself as a mediator of relations in the network (betwenness centrality). Table 08 presents the most central authors in both concepts. Regarding the degree centrality measure, stands out the researchers Robert B. Handfield (North Carolina State University) and Roger Schroeder (University of Minnesota). The first one established 24 direct ties to the production of their articles, while the second 23. Another indicator of centrality, the betwenness centrality, evaluates the ability of the author to participate in different group on the same network and can also indicate those actors that control the flow of information within the network. Roger Schroeder stands out and also Aleda Roth (from Clemson University).

Table 08 - Authors with the highest centrality

Researcher	Degree Centrality	Researcher	Betwenness Centrality
Handfield, R. B.	24	Schroeder, R. G.	99.357
Schroeder, R. G.	23	Roth, A.	81.835
Roth, A.	22	Boyer, K. K.	81.404
Boer, H.	19	Mallick, D. N.	79.322
Boyer, K. K.	18	Field, J. M.	72.358
Samson, D.	18	Faull, N. H. B.	65.565
Rungtusanatham, M. J.	16	Handfield, R. B.	43.823
Swink, M.	16	Martinez, V.	39.485
Voss, C.	15	Ritzman, L. P.	38.146
Bendoly, E.	14	Shah, R.	37.770

Neely, A.	14	Voss, C.	37.248
Lee, T. S.	14	Bititci, U. S.	36.741

Source: Search Results

It can be noted that some authors combine high degree centrality with high betweenness centrality. On the other hand, others who did not have a great degree of centrality, presented a great ability to intermediate relationships in the network, and an example is the researcher Debasish Mallick . Researchers like him have a central location on the network that allow them to mediate many relationships, even though it did take large amounts directly. Other researchers, who have a high degree centrality and also a high betweenness centrality combine the two characteristics: they have many other direct relationships and indirect relationships.

6. Conclusions and Recommendations

This study assumed that scientific knowledge is socially constructed (Kuhn, 1978; POPPER, 1972) and sought to analyze aspects of productivity and scientific collaboration of POM field. The literature in the field was very stratified and in terms of institutions and countries, such concentration proved even more evident. Thus, the results of the present study allowed the identification of institutions and researchers who contributed most to the scientific development of the field. This identification may enhance the interaction between institutions and researchers. Such information may be valuable to students who are evaluating and selecting institutions for their training in the area of operations. Additionally, the map of institutions, researchers and research groups can serve as a target for publishers, colleges and companies in the quest for institutions and researchers to develop projects in the area of teaching, researching and consulting.

It was also observed that the average number of ties of researchers co-authorship network grew, indicating that the authors now tend to relate more if compared to the past. However, the network density decreased with the increase of the network, ie, the amount of ties actually built between the authors did not follow the increase of possible ties in the network, leading to further fragmentation of the same. Furthermore, the results showed that the most central authors in the network are the researchers who have developed a denser network and thus seek to develop their work more cooperatively. The recommendations for future studies can be made, such as the study of other forms of relationships between researchers (more qualitative) as researchers seek to build their networks of co-authorship. This type of study applied to journals and international events could bring significant contributions to the understanding of the dynamics of POM field.

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