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Mapping the Field of Product Lifecycle Management: A Bibliometric Study

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Abstract: *In today's competitive economy the systematic development and management of industrial products has become a central issue for manufacturers. In this paper, the field of product lifecycle management is mapped to tribute to its colorful past and promising future. Therefore, a set of well-established bibliometric methods – i.e. (1) citation analysis, (2) co-citation analysis, (3) bibliographic coupling analysis, (4) co-author analysis, and (5) co-word analysis – provides a suitable methodological vehicle. Essential results comprise (1) the documents, authors, and journals with the most impact, (2) the intellectual structure, (3) the intellectual structure of emerging literature, (4) the social structure, and (5) the topics associated with the field. Grounded on these insights, potential avenues for further research are highlighted. Within the characteristic limitations of this kind of literature review, the paper offers content-wise, method-wise, and discipline-wise contributions.*

Keywords: *Product lifecycle management, PLM, manufacturing industries, literature review, bibliometric study*

Introduction

In today's competitive economy the systematic development and management of industrial products has become a central issue for manufacturers (Terzi et al. 2010; David and Rowe 2015; Stark 2015). Conformable to the highly cited understanding of Stark (2015, p.1), product lifecycle management is defined as a “business activity of managing, in the most effective way, a company's products all the way across their lifecycles”. In this product lifecycle, activities of product design and manufacturing (i.e. beginning-of-life stage), tasks of distribution, use, and support (i.e. middle-of-life stage), and works of retiring and disposing (i.e. end-of-life stage) are accomplished (Terzi et al. 2010; Stark 2015). From an economic perspective, an estimated product lifecycle management market of around 65 billion US-Dollar in five years from now on (Global Industry Analysts Inc. 2016) underlines the vital role of the 21st century paradigm for product realization (Stark 2015).

With product lifecycle management coming to age on the one hand (David and Rowe 2015) and being predicted to have a glowing future by novel technologies such as the Internet of Things, Big Data analytics, and cloud computing on the other hand (Terzi et al. 2010), a review of the field seems both timely and relevant. Increasingly understood as socio-technical phenomenon (Bostrom and Heinen 1977; David and Rowe 2015), the information systems domain seems predestinated to attend this matter. Despite brilliant knowledge syntheses from the outset (e.g., Terzi et al. 2010; David and Rowe 2015), qualitative structured literature reviews are inherently restricted by scope and rigor (Zupic and Cater 2015). In contrast, quantitative bibliometric literature reviews to explore hidden structures and furthermore overcome these limitations (Zupic and Cater 2015) are practically non-existent. Moreover, a major challenge is rooted in the deeply distributed research and practice activities related to the lifecycle of industrial products that merged in the field of product lifecycle management (David and Rowe 2015; Pinquié et al. 2015). Summarizing this need for a mapping of the field (Bhatt et al. 2015; David and Rowe 2015), the guiding research question (RQ) for this paper is stated as follows: *“How is the field of product lifecycle management in manufacturing industries organized?”*

Therefore, this paper applies a set of well-established bibliometric methods according to the single-source reference of Zupic and Cater (2015). In particular, bibliometric data from the largest scholarly database for peer-reviewed literature are compiled, analyzed, visualized, and interpreted (Zupic and Cater 2015). Such an approach is chosen because the demand for diversity in the information systems domain has been expressed by Benbasat and Weber (1996) in general and by Fettke (2006) for literature reviews in particular.

The paper continues with the research background in terms of product lifecycle management and existing literature reviews. Next, the research methodology including an overview on bibliometric studies and the applied workflow is ushered. The subsequent two sections focus on presentation and discussion of the bibliometric study results, clustered by analysis type. The paper closes with a summary, contributions, limitations as well as potential directions for further research.

Research Background

Nature of Product Lifecycle Management

In essence, Cao and Folan (2012) describe the history of product lifecycle management as four-level evolution: Main development steps range from (1) essential product-centric IT tools (e.g., computer-aided design CAD) in the 1970s, to (2) more general product-centric IT applications (e.g., computer-aided quality CAQ) in the 1980s, to (3) product data management (PDM) in the 1990s, and nowadays (4) product lifecycle management (PLM) since the 2000s (Cao and Folan 2012). The birth of the field may be the establishment of the International Conference of Product Lifecycle Management and the International Journal of Product Lifecycle Management in 2003 respectively 2005 (Pinquié et al. 2015). Notwithstanding the field resorts to related research communities such as new product development, product-service-system engineering, or computer science up to today (Pinquié et al. 2015). Beyond the given conceptualization of Stark (2015) seminal definitions have been formulated by Saaksvuori and Immonen (2002), Ameri and Dutta (2005), Grieves (2006), Eigner and Stelzer (2008), and Terzi et al. (2010) over the years. In their comprehensive article, Corallo et al. (2013) emphasize the diversity of elements of product lifecycle management. Nevertheless they agree on (1) managerial features (e.g., integrated approach), (2) technological features (e.g., product information backbone), and (3) collaborative features (e.g., integrating people, process, and data) as distinctive elements (Corallo et al. 2013). In brief, from an originally technical understanding, product lifecycle management is increasingly grasped as management approach (Terzi et al. 2010; David and Rowe 2015). Accordingly, the field is becoming a major area of interest in the information systems domain (Nambisan 2003; Nambisan 2013; David and Rowe 2015).

Existing Literature Reviews

Looking for available literature reviews relating to product lifecycle management within the last decade (Webster and Watson 2002), fundamentally two distinct publication streams can be detected, qualitative and quantitative analyses: Firstly, concerning qualitative literature reviews, Terzi et al. (2010) created a pioneering piece recapitulating the preceding and future role of product lifecycle management. Furthermore, a set of shorter state-of-the-art contributions (Abramovici 2007; Garetti et al. 2007; Cheung and Schaefer 2009) with no structured literature search approach mainly published as book chapters becomes nascent. The work of Ming et al. (2005) on the state-of-the-art of product lifecycle management in collaborative contexts can be counted to the group of reviews on specific topics. The most recent contribution is made by David and Rowe (2015) who systematically review publications from different communities and derive avenues for further research. Secondly, regarding quantitative analyses, publications come considerably more rarely into sight. Solely Bhatt et al. (2015) conducted a quantitative study on publications from the International Conference of Product Lifecycle Management. Other quantity-oriented publications are solely partially tangent to the field, such as Kalluri and Kodali (2014) who review new product development research or Oliveira et al. (2015) who examine the field of product-service-systems.

Highly appreciating the attempts to map the complex field of product lifecycle management, extant research works are exposed to shortcomings: For instance, as most fitting qualitative contribution, David and Rowe (2015) merely map the field selectively and communicate their findings in French language. As most relevant quantitative contribution, Bhatt et al. (2015) exhibit a very narrow scope of literature and provide few implications for action. Briefly, a consistent mapping of the field is hardly existent (Bhatt et al. 2015; David and Rowe 2015). To shrink this research gap, the paper at hand reports on a conducted bibliometric study.

Research Methodology

Overview on Bibliometric Studies

Zupic and Cater (2015) differentiate three fundamental types of literature reviews: Qualitative studies, meta-studies, and bibliometric studies. For this paper, a bibliometric study was selected upon three rationales: Firstly, within the increasing number of publications, quantitative analyses can be seen as value-adding methods (Zupic and Cater 2015). Especially the holism and interdisciplinary character of the subject at hand (Terzi et al. 2010) put such methods forward. Secondly, concrete metrics assist to overcome potential biases of interpretive, qualitative reviews (Zupic and Cater 2015). Thirdly, the diversity in review methods in the information systems domain needs to be strengthened as Fettke (2009) unveils that zero percent of reviews published in the journal *Business & Information Systems Engineering* exhibit quantitative character.

In short, the purpose of bibliometric methods is to “examine how disciplines, fields, specialties, and individual papers are related to one another” (Zupic and Cater 2015, p.429). Following Khan and Wood (2016) these methods can be assigned to the group of social network analyses, conventional literature reviews, and topic analyses. Pristine research works (e.g., Cattell 1906; Pritchard 1969; Broadus 1987) demonstrate that bibliometric methods feature a long tradition. However, these days two major factors contribute to taking on greater significance: For one new databases aim to provide a consistent single-source data basis, for another novel tools afford an intelligent data processing (van Eck and Waltman 2014; Zupic and Cater 2015). Such methods have given proof of making contributions in distinct research communities such as business and management (e.g., Olczyk 2016) or innovation and technology (e.g., Remneland Wikhamn and Wikhamn 2013). In the information systems domain an emerging number of publications in quality outlets (e.g., Beverungen 2011; Simon et al. 2013; Khan and Wood 2016) demonstrates that these types of works are on the rise.

For this paper, the single-source reference for bibliometric methods compiled by Zupic and Cater (2015) is used as sound guidance. More precisely, the recommended workflow is pursued: (1) Development of research design, (2) compilation of bibliometric data, (3) analysis, (4) visualization, and (5) interpretation. Scholars providing methodic guidance for qualitative (e.g., vom Brocke et al. 2009; vom Brocke et al. 2015) and quantitative (e.g., Börner and Polley 2014; Thiede 2017) reviews alike plea for rigor, thus this paper aims for end-to-end transparency. Beyond, each step outlined hereinafter is augmented by further methodological guidance (e.g., Webster and Watson 2002; Rowe 2014; Schryen 2015).

Workflow for Bibliometric Studies

Step 1: Development of research design. Within the objective of an initial mapping of the field and the restricted space, this paper strives for the most established and insightful analyses: In particular, the documents, authors, and journals with the most impact (RQ1), the intellectual structure (RQ2), the intellectual structure of emerging literature (RQ3), the social structure (RQ4), and the topics associated with the field (RQ5) are targeted (Zupic and Cater 2015). Hence, (1) a citation analysis, (2) a co-citation analysis, (3) a bibliographic coupling analysis, (4) a co-author analysis, and (5) a co-word analysis serve as proper research design (Zupic and Cater 2015).

Step 2: Compilation of bibliometric data. Basically, several databases such as Web of Science by Thomson Reuters, Scopus by Elsevier, or Google Scholar by Google are qualified for the data provision. For the selection process, comparative research on databases (Bakkalbasi et al. 2006; Falagas et al. 2008) was consulted and finally Scopus which is according to their own statements “the largest abstract and citation database of peer-reviewed literature” (Elsevier 2017) was selected. One critical reason was that the International Journal of Product Lifecycle Management as essential source is currently not included in Web of Science (Thomson Reuters 2017). The compilation of the data – accomplished on July 31, 2017 – proceeded as follows (vom Brocke et al. 2009): With product lifecycle management as unique term (Pinquié et al. 2015), a database search in title, abstract, and keywords seemed adequate to grasp the literature ($\Sigma 4,055$ hits). Targeting recent contributions, results were reduced involving a ten year time frame ($\Sigma 3,091$ hits). For the sake of the most enduring pieces, these hits were restricted to journals ($\Sigma 1,134$ hits) and limited to results published in English ($\Sigma 1,018$ hits). Thereafter, obviously non-relevant scientific domains ($\Sigma 830$ hits) and journals ($\Sigma 552$ hits) were removed. Bibliometric data were downloaded.

Steps 3/4/5: Analysis/visualization/interpretation. Subsequent steps were prepared by quality check and reworking of bibliometric data. So far not known articles were screened for fit. Concerning the analysis and visualization diverse tools (e.g., CiteSpace, Gephi, Pajek, and VOSviewer (van Eck and Waltman 2014)) are available. The software VOSviewer (van Eck and Waltman 2010; Waltman et al. 2010) was chosen as this tool supports the developed research design and has proven as successful in several similar cases (e.g., Khan and Wood 2016). Particularly for the important step of interpreting, several focus groups (Morgan 1988; Tremblay et al. 2010) helped to discuss the findings and draw implications (Zupic and Cater 2015). Here, senior researchers for experience and junior scholars for an unbiased mindset were included as stressed by Zupic and Cater (2015).

Bibliometric Study Results

Documents, Authors, Journals with the Most Impact: Citation Analysis

Table 1 visualizes the findings of the accomplished citation analysis. A citation analysis “estimates influence of documents, authors, or journals through citation rates” (Zupic and Cater 2015, p.432). Thus, this type of bibliometric analysis enables to answer the first research question (RQ1) “*What documents, authors, and journals have the most impact in the field of product lifecycle management?*”. In line with the posed research question, documents, authors, and journals were used as units of analysis. It should be noted that for this sub-section no network visualization was selected as direct citation networks are commonly parsimonious (Zupic and Cater 2015).

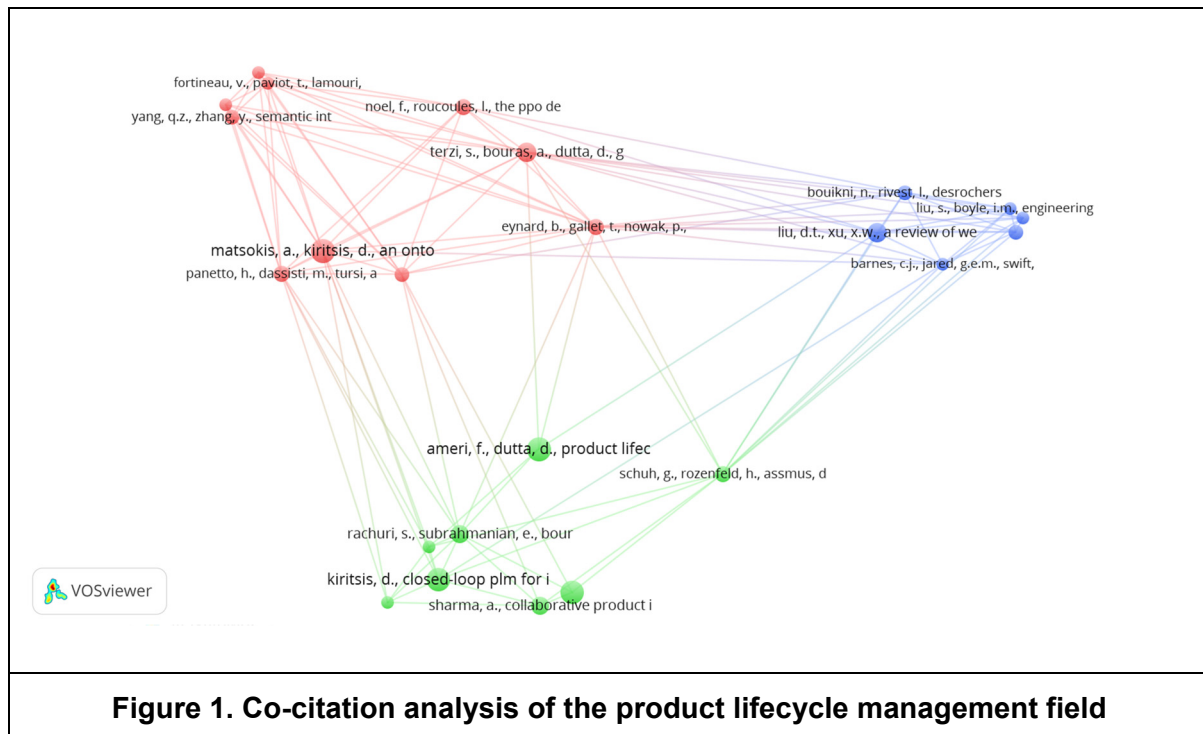
To summarize Table 1, the paper on intelligent products by Meyer et al. (2009) as most cited document, senior scholar Dimitris Kiritsis from the École Polytechnique Fédérale de Lausanne as most cited author, and the IT-oriented outlet Computers in Industry as most cited journal in the field of product lifecycle management can be seen. Examining the quantity of citations, the field can be classified as established, compared to other fields such service science where most cited documents show around 400 citations (Beverungen 2011). Studying in contrast their distribution, the citations are rather unequally distributed. Particularly author and journal citations clearly expose a “star” author (Dimitris Kiritsis) and a “star” journal (Computers in Industry) with the next author respectively next journal accounting for around the half respectively a third of received citations. Generally, it becomes evident that a large share of the items in Table 1 comprises a rather technical focus. Research is especially published in strongly IT-related journals (e.g., Computers in Industry) or specific outlets (e.g., International Journal of Computer Integrated Manufacturing). These enumerations suggest the field’s most impactful documents, authors, and journals in an unambiguous manner, yet imply that “much that is read is not cited, and citation behavior can be biased” as noted by Culnan (1987, p.342).

Table 1. Citation analysis of the product lifecycle management field			
#	<i>Documents (no. of cit.)</i>	<i>Authors (no. of cit.)</i>	<i>Journals (no. of cit.)</i>
1	Meyer et al. 2009 (226)	Kiritsis, D. (700)	Computers in Industry (1600)
2	Kiritsis 2011 (176)	Främling, K. (359)	CAD Computer-Aided Design (564)
3	Kumar/Putnam 2008 (137)	Holmström, J. (292)	Int. J. of Computer Integrated Manufacturing (424)
4	Shen et al. 2010 (130)	Rivest, L. (290)	Int. J. of Product Lifecycle Management (371)
5	Jun et al. 2007 (119)	Eynard, B. (250)	CIRP Annals Manufacturing Technology (353)
6	Baxter et al. 2007 (111)	Foufou, S. (246)	Advanced Engineering Informatics (288)
7	Terzi et al. 2010 (106)	Sriram, R. D. (245)	Int. J. of Production Economics (253)
8	Vanlande et al. 2008 (104)	Meyer, G. G. (226)	Int. J. of Advanced Manufacturing Technology (227)
9	Maropoulos/Ceglarek 2010 (101)	Vezzetti, E. (196)	Robotics and Computer-Integrated Manufacturing (217)
10	Panetto et al. 2012 (95)	Bouras, A. (194)	Research in Engineering Design (216)

Intellectual Structure: Co-citation Analysis

Figure 1 illustrates the result of the conducted co-citation analysis. A co-citation analysis “connects documents, authors, or journals on the basis of joint appearances in reference lists” (Zupic and Cater 2015, p.432). Consequently, the second research question (RQ2) “*What is the intellectual structure of the field of product lifecycle management?*” can be addressed with such an analysis. For the generation of the co-citation network, the focus lay on the content-oriented unit of analysis document. For an expressive visualization, key parameters were set to a Minimum number of citations of a cited reference $m=3$ and a Number of cited references to be selected $n=24$. In addition, the Full Counting Methodology was used. In the resulting network a node represents a document and the node size corresponds with the number of citations. Furthermore, VOSviewer uses distance-based visualization, consequently two documents appear closer in the visualization if these two documents are cited together in a third document more often (van Eck and Waltman 2010; Waltman et al. 2010).

Closer inspection of Figure 1 unveils three co-citation clusters, shaded in different colors. The first cluster (red) comprises documents around Matsokis and Kiritsis (2010), the second cluster (blue) exhibits works around Liu and Xu (2001), and the third cluster (green) features documents around Kiritsis (2011). Externally, the clusters are quite self-contained and delimited from one another. Internally, the clusters can be qualified as rather dense. For instance, Matsokis and Kiritsis (2010) and Panetto et al. (2012) show a strong connection in the co-citation network. Both documents approach product lifecycle management ontology-based, thus show high content-oriented similarity. This corroborates the statement of Zupic and Cater (2015) who introduce co-citation as measure for similarity. Generally, from a content-oriented viewpoint, the intellectual structure is dominated by conceptual (e.g., Matsokis and Kiritsis 2010) and technical (e.g., Kiritsis 2011) works on product lifecycle management. By way of contrast empirical and theory-driven research is mainly missing. As publishing and citation processes usually take time, it needs to be remarked that the network maps the field with certain temporal delay (Zupic and Cater 2015).



Intellectual Structure of Emerging Literature: Bibliographic Coupling Analysis

Figure 2 depicts the outcome of the performed bibliographic coupling analysis. A bibliographic coupling analysis “connects documents, authors, or journals on the basis of the number of shared references” (Zupic and Cater 2015, p.432). Hence, such an analysis technique affords to answer the third research question (RQ3) “*What is the intellectual structure of emerging literature of the field of product lifecycle management?*”. As for the previous co-citation analysis, again documents serve as insightful units of analysis. For the creation of the bibliographic coupling network, the visualization parameters were adjusted as follows: Minimum number of citations of a document $m=5$ and a Number of documents to be selected $n=30$. Additionally, in turn the Full Counting Methodology was applied. In the resulting bibliographic coupling network with distance-based visualization, documents are represented by nodes with the node size matching with the quantity of received citations. A short distance between two documents (i.e. the length of the edges) can be viewed as a good match of their reference lists (van Eck and Waltman 2010; Waltman et al. 2010).

From the Figure 2 four individual, differently colored bibliographic coupling clusters become nascent. Dominant documents in these clusters are Terzi et al. (2010) [green cluster], Maropoulos and Ceglarek (2010) [red cluster], Panetto et al. (2012) [yellow cluster], and Demoly et al. (2011) [blue cluster]. Compared to the previous co-citation network, the clusters of the bibliographic coupling network can be described as less distinct and more interconnected. Beyond, it can be seen that, for example, Panetto et al. (2012) and El Kadiri and Kiritsis (2015) exhibit a tight relationship in the network. Both documents focus on ontologies in the context of product lifecycle management, hence this can be construed as measure for similarity, which goes in line with Zupic and Cater (2015). The intellectual structure of emerging literature is also shaped by conceptual (e.g., Panetto et al. 2012) and technical (e.g., Cao et al. 2009) works, complemented by reviews on specific topics (e.g., El Kadiri and Kiritsis 2015). Furthermore, it is assembled by few authors (or author teams) such as Hui Cao and Frédéric Demoly. In contrast, empirical and theory-driven research is practically non-existent. As there is no retardation in comparing reference lists, the network at hand is appropriate to describe the structure of nascent literature (Zupic and Cater 2015).

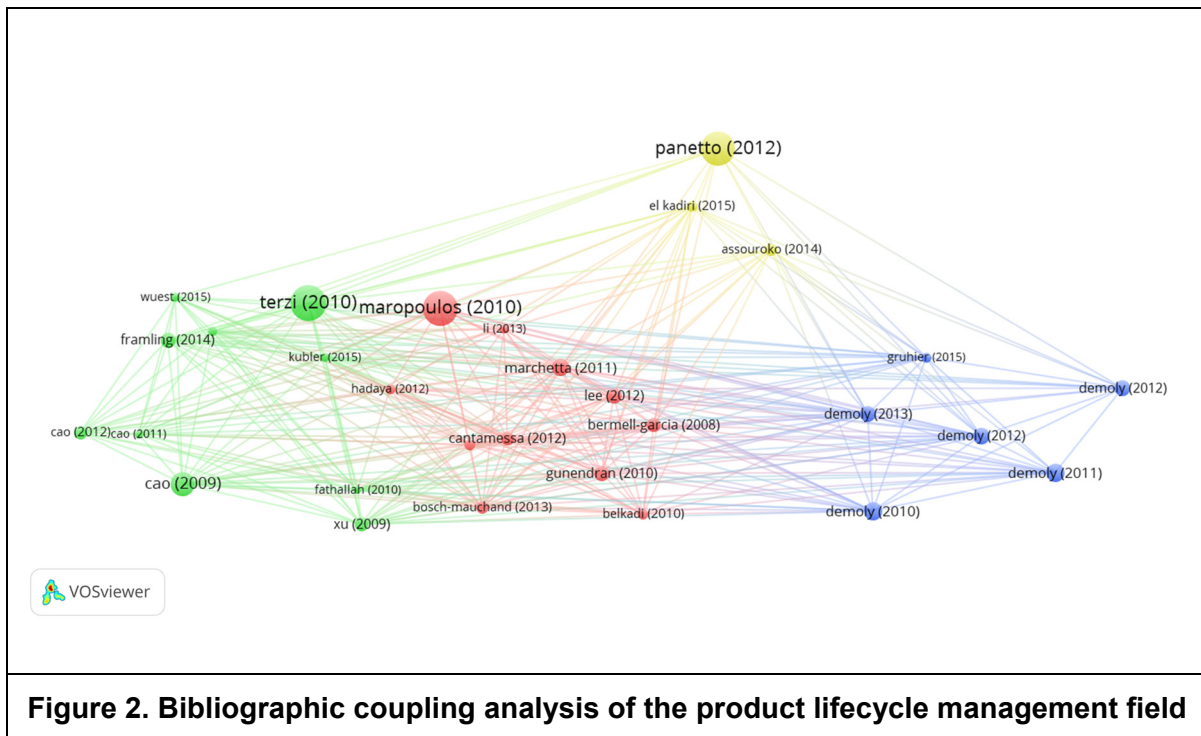


Figure 2. Bibliographic coupling analysis of the product lifecycle management field

Social Structure: Co-author Analysis

Figure 3 demonstrates the result of the carried out co-author analysis. A co-author analysis “connects authors when they co-author the paper” (Zupic and Cater 2015, p.432). Thus, the posed fourth research question (RQ4) “*What is the social structure of the field of product lifecycle management?*” can be answered with a co-author analysis. For this particular study, a unit of analysis at an author level, rather than an increasingly anonymous organization or even country level, was decided. For a revelatory visualization of the co-author analysis, the network parameters were tuned to a Minimum number of documents of an author $m=2$, Minimum number of citations of an author $n=10$, and Number of authors to be selected $o=63$. With regard to the counting approach, the Full Counting Methodology was harnessed. In the co-author analysis figure, the nodes represent authors and the size of the nodes serve as measure for the number of authored documents. The proximity of two authors on the other hand is higher if they co-authored more documents together (van Eck and Waltman 2010; Waltman et al. 2010).

In Figure 3 nine different inked co-authorship clusters become evident. Thereby, each co-author cluster comprises one (e.g., Dimitris Kiritsis for the green cluster) or more (e.g., Frédéric Demoly and Samuel Gomes for the brown cluster) key authors. The clusters themselves are organized rather independently which implies a rather loose social structure and weak collaboration beyond the borders of the individual clusters. In particular, the strong connection between Dimitris Kiritsis and Aristeidis Matsokis, for example, can be detected which seems plausible as both scientists have been working at the École Polytechnique Fédérale de Lausanne. However, at this point it is remarkable that co-authorship needs be understood rather as measure for co-authoring documents than for co-working on product lifecycle management as authorships are often given upon social and political reasons (Zupic and Cater 2015).

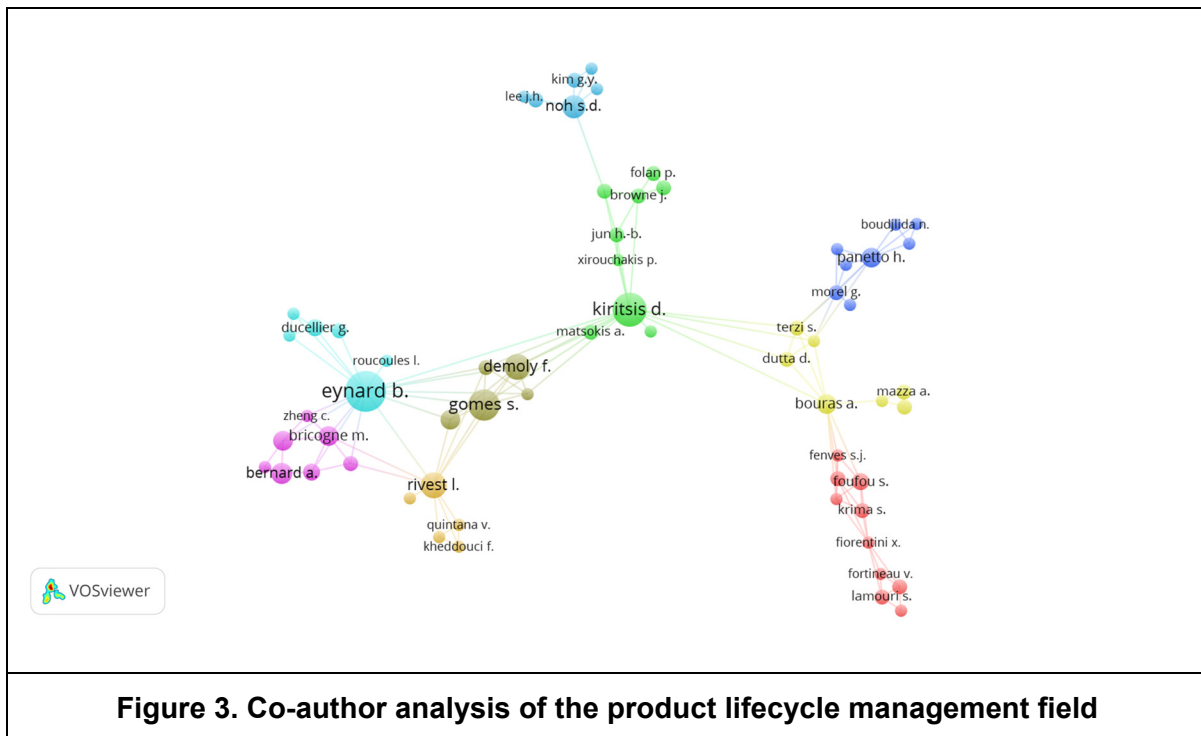


Figure 3. Co-author analysis of the product lifecycle management field

Topics Associated: Co-word Analysis

Finally, Figure 4 displays the outcome of the undertaken co-word analysis. A co-word analysis “connects keywords when they appear in the same title, abstract, or keyword list” (Zupic and Cater 2015, p.432). Consequently, co-word analyses are suitable to address the fifth research question (RQ5) “*What are the topics associated with the field of product lifecycle management?*”. For this last work, the co-word analysis was applied to words appearing in the author keywords field as these describe the content more precisely than standard classification systems. Beyond, parameters were set to a Minimum number of occurrences of a keyword $m=3$ and a Number of keywords be selected $n=40$ to generate an informative, yet manageable network. For this ultimate analysis, also the Full Counting Methodology was employed. In the originating co-word analysis network, each node represents a key word, the node size corresponds with the number of occurrences. In the distance-based network representation, two key words adjoin closer the more often they occur together in documents (van Eck and Waltman 2010; Waltman et al. 2010).

It can be seen from the data in Figure 4 that the borders of the many co-word clusters were blurring this time, hence a monochromatic representation seems proper. Naturally, terms of product lifecycle management as center of the network can be seen. Furthermore, exempli gratia, strong relationships to notions of information management and knowledge management are identifiable. From a technology perspective, the important role of the Internet of Things and accordingly closed-loop product lifecycle management emerges. Nevertheless, despite the nomenclature of product lifecycle management, the field seems to focus on applications in the early lifecycle stages such as product development and manufacturing and corresponding sub-functions like simulation. This approach uses actual paper content instead of meta-data like the antecedent analyses (Zupic and Cater 2015). Special consideration however is necessary as “words can appear in different forms and can have different meanings” (Zupic and Cater 2015, p.432).

Table 2. Main findings of the bibliometric study	
<i>The documents, authors, and journals with the most impact...</i>	comprise the paper on intelligent products by Meyer et al. (2009), senior scholar Dimitris Kiritsis from the École Polytechnique Fédérale de Lausanne, and the IT-oriented outlet Computers in Industry with generally imbalanced citation distributions resulting in citation "stars".
<i>The intellectual structure...</i>	comprises three co-citation clusters around the documents Matsokis and Kiritsis (2010), Liu and Xu (2001), and Kiritsis (2011) with externally rather self-contained and delimited and internally rather dense clusters and is shaped by conceptual and technical works lacking in empirical and theory-driven research.
<i>The intellectual structure of emerging literature...</i>	comprises four bibliographic coupling clusters around the documents Terzi et al. (2010), Maropoulos and Ceglarek (2010), Panetto et al. (2012), and Demoly et al. (2011) with less distinct and more interconnected clusters, is dominated by conceptual and technical – missing empirical and theory-driven – research, and is assembled by few authors.
<i>The social structure...</i>	comprises nine co-authorship clusters around one (e.g., Dimitris Kiritsis) or more leading authors (e.g., Frédéric Demoly and Samuel Gomes) with rather independently organized clusters.
<i>The topics associated...</i>	comprise many co-word clusters with a spectrum of topics and blurring borders including strong relationships to information management and knowledge management, the Internet of Things technology, and applications in early lifecycle stages such as product development and manufacturing.

Avenue 1 based on methodological void and action-knowledge conflict. In the first place, it seems worthwhile to increasingly tribute to the complex phenomenon product lifecycle management in its real-world environment. The co-citation analysis, bibliographic coupling analysis, and co-word analysis unveiled that product lifecycle management is mainly investigated from conceptual and technical perspectives. Future research may increasingly study how manufacturing enterprises organize the lifecycle management of their industrial products in a complex real-world setting. Here, strategies of inquiry such as case study research (Yin 2003) or action research (Baskerville and Wood-Harper 1998) seem well-qualified.

Avenue 2 based on theory application void. In the second place, an ameliorated application of theories on the phenomenon product lifecycle management seems valuable. The co-citation analysis, bibliographic coupling analysis, and co-word analysis indicated that theory-infused research is not widely distributed in the knowledge base. An application of theories in prospective research endeavors can generate new insights and make a substantial contribution towards a technology in use. For instance, the socio-technical systems theory (Bostrom and Heinen 1977) or the organizational information processing theory (Galbraith 1973) may represent qualified theoretical perspectives.

Avenue 3 based on knowledge void. In the third place, an increasing absorbance of relevant digital technologies seems desirable. The co-citation analysis, bibliographic coupling analysis, and co-word analysis disclosed that the field – with the exception of the Internet of Things technology – mainly deals with traditional topics of information management. Research needs to keep pace with the profound further development of product development and product lifecycle management technologies. For example, the role of Big Data analytics (Chen et al. 2012) or cloud computing (Yang and Tate 2012) in the context of product lifecycle management may represent fruitful areas of interest.

For embedding these findings and implications in existing literature, the introduced reviews serve as reference points. Whereas more earlier works (e.g., Abramovici 2007; Garetti et al. 2007) plea for a more overarching scope of product lifecycle management, more recent works (e.g., Terzi et al. 2010; David and Rowe 2015) highlight the demand for a socio-technical – rather than a technical – approach to the field. Thus, the accomplished analyses corroborate – and moreover quantify – the ideas of David and Rowe (2015, p.273) as most insightful contribution who recommend to enhance “our understanding of human and managerial dimensions” of product lifecycle management. An introduction and strengthening in the information systems domain seems opportune.

Concerning the second objective, scholarly quality assessment is crucial for any kind of research. As in all conscience no explicit methodic aid for the assessment of bibliometric studies is available, this paper refers to the seminal article by vom Brocke et al. (2009) where classic criteria validity and reliability are discussed in the context of literature reviews: Validity is described as the degree of accordance of actually searched and purposed literature (vom Brocke et al. 2009). For this study, profound reflections on the search process in general and the databases in particular contributed to increase validity. However, validity reducing aspects – as outlined in the limitations – apply which should be factored in. Reliability deals with repeatability of the process solely with the information presented (vom Brocke et al. 2009). To augment reliability, a detailed protocol documented the activities and process repetitions using this protocol came up with congruent results – aside from slightly fluctuating databases (vom Brocke et al. 2015). In sum, this study offers valid and reliable findings that afford to grasp the field en bloc, complementing qualitative reviews rather than substituting them (Beverungen 2011; Zupic and Cater 2015).

Conclusion

The research presented in this paper was undertaken to map the field of product lifecycle management in manufacturing industries leveraging bibliometric methods. Consolidating the findings of the complex individual analyses, it can be concluded that the field at hand is characterized by (1) selected prominent documents, authors, and journals, (2/3) a conceptual and technical research-dominated knowledge base and knowledge base of emerging literature, (4) a rather loose social structure, and (5) a variety of associated topics. These insights in turn evoke the demand for further empiricism-based, theory-driven, and digital technologies-focused research.

To research, the paper contributes threefold, (1) content-wise, (2) method-wise, and (3) discipline-wise: Firstly and foremost, this work is likely to be the first bibliometric study for the field embracing such a comprehensive scope. Thus, for beginners it enables a jump-start and for experts hidden structures are unveiled and novel implications (Culnan 1986) are provided. Secondly, Benbasat and Weber (1996) plea for diversity in the information systems domain. Hence, the prevailing qualitative structured literature reviews are enriched with a bibliometric study helping to establish this methodological approach. Here, this paper can be seen as valuable, repeatable example. Thirdly, the necessity of interdisciplinary research is highlighted by Webster and Watson (2002). With links to bordering fields from near (e.g., computer science) and far (e.g., engineering) communities, this paper fosters this demand as well.

Indeed, with a mapping of the academic literature the contribution to research overweighs. Yet, with product lifecycle management as applied approach by definition, to practice the necessity and utility of the approach is shown likewise. Additionally, most important and established information sources such as documents, authors, and journals are unraveled for executives and consultants working in manufacturing industries.

These contributions are precious in spite of potential limitations: Certainly, a major challenge is linked to the chosen database (Zupic and Cater 2015). Its coverage and data quality profoundly implies the results quality and may partially distort them. Furthermore, minor obstacles are associated with the bibliometric methods themselves (Zupic and Cater 2015). For example, citation analyses generally show a bias towards older works. As for any kind of reviews, conceivable weaknesses arise from the selection of search criteria (vom Brocke et al. 2015).

Looking ahead, firstly, more advanced analytic (e.g., time-related) and visualization (e.g., interactive) methods may be harnessed for even richer and deeper insights. Secondly, for the purpose of triangulation a comparison with other databases and analysis and visualization tools can augment the validity of the findings. With respect to the introduced third category of literature reviews, meta-analyses in the field of product lifecycle management are currently still an untouched field.

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