A bibliometric analysis of the product line design problem

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Abstract

In the product design problem, firms aim to find suitable configurations of product attributes with the objective of increasing their participation in the marketplace. This problem belongs to the field of quantitative marketing and is considered a NP-Hard problem, due to its wide search space for an optimal solution. Among the related literature, there are different methodologies to address this problem, gaining ground those that apply metaheuristics, with an emphasis in Genetic Algorithms. The main aim of this work is to present an overview of the most significant contributions in this area using a bibliometric analysis approach. The paper uses Scopus database and Web of Science Core Collection, in order to obtain leading and the most influential articles, conferences papers, journals, authors, institutions and countries. The results highlight Kwong, C.K. as the most productive author while Nagamachi M. is the most influential author. Furthermore, China is the leading country in this research field. The use of Genetic Algorithms in the solutions of the Product Design Problem is a growing area of study with important development of methodologies and approaches.

Keywords: bibliometric, product line design problem, product line development, new product line, product line design, genetic algorithm

JEL codes. C00, C02

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Un análisis bibliométrico del problema de diseño de línea de productos

Resumen

En el problema del diseño de productos, las empresas tienen por objetivo encontrar configuraciones adecuadas de los atributos del producto con el objetivo de incrementar su participación en el mercado. Este problema pertenece al campo de la mercadotecnia cuantitativa y es considerado un problema NP-Hard, debido a su amplio espacio de búsqueda para una solución óptima. Entre la literatura relacionada, existen diferentes metodologías para abordar este problema, ganando terreno las que aplican metaheurísticas, con énfasis en Algoritmos Genéticos. El objetivo principal de este trabajo es presentar una visión general de las contribuciones más significativas en esta área utilizando un enfoque de análisis bibliométrico. El artículo utiliza la base de datos Scopus y la Colección principal de Web of Science, con el fin de obtener los principales y más influyentes artículos, conferencias, revistas, autores, instituciones y países. Los resultados destacan a Kwong, C.K. como el autor más productivo, mientras que Nagamachi M. es el autor más influyente. Además, China es el país líder en este campo de investigación. El uso de Algoritmos Genéticos en las soluciones del Problema de Diseño de Producto es un área de estudio en crecimiento con un importante desarrollo de metodologías y enfoques.

Palabras clave: Bibliométrico, problema de diseño de la línea de productos, desarrollo de la línea de productos, nueva línea de productos, diseño de la línea de productos, algoritmo genético

Códigos JEL: C00, C02

1. INTRODUCTION

New product development is one of the most recurrent strategies that companies use to remain competitive in the marketplace and for increasing profits. During the initial design stages, the decision makers seek to create products that have more significant potential for success through better and robust design. This problem is known as The New Product Line Design Problem (PLD), and belongs to the area of quantitative marketing, the objective is to select the attributes of the products that make up the product line, in order to maximize the income that will result from the different types of preferences within the client population (Bertsimas & Mišic, 2017). This problem is of vital importance for the success of a company, and considerable research effort has been devoted to modeling and solving the PLD problem.

Most approaches to the PLD problem model it as an optimization problem and assume a customer behavior model of first choice; some examples are (Siskos, Yannis, Grigoroudis & Matsatsinis, 2004; Kohli, Rajeev; Krishnamurti, 2008; Green & Krieger, 2015). There are different areas that engage in the development of new products design, such as simulation models (Tsafarakis & Matsatsinis, 2010; Leyva-Lopez, Martín, Ahumada-Valenzuela, & Romero-Serrano, 2018), engineering (Nagamachi, 1995; Zeng, Li, & Peng, 2006; Garg, Gao, Panda, & Mishra, 2017) and supply chain configuration and manufacturing (Huang, Zhang, & Liang, 2005; Ruiz & Maroto, 2006; Yildiz, 2009;

Alizadeh Afrouzy, Nasseri, & Mahdavi, 2016; Etgar, Gelbard, & Cohen, 2017).

In the literature, the PLD problem has been tackled through several approaches, Tsafarakis (2010) carried out an extensive review comparing the general solution methods. Several of the heuristic methods always find optimal or almost optimal solutions, including Coordinate Ascent, Genetic Algorithms, Simulated Annealing, Greedy Heuristic, Divide-and-Conquer Heuristic, Product-Swapping Heuristic, Dynamic Programming Heuristic, Beam Search Heuristic, and Nested Partitions Heuristic. The comparisons benefit from advances that allow calculating optimal solutions guaranteed to problems that are too large for a complete enumeration (Belloni et al., 2008). Four of the heuristic methods work particularly well, always reaching almost optimal solutions even in the presence of measurement errors: Simulated Annealing, Product-Swapping Heuristic, Divide-and-Conquer Heuristic, and Genetic Algorithms. Particulary the last one is relevant for solving complex problems (Steiner & Hruschka, 2018) and Balakrishnan and Jacob (2001) applied it for the first time to find the optimization of the product design problem.

The genetic algorithms (AG) are based on the biological process of natural selection, the first process is to define the characteristics of the individual, whose information is stored in chromosomes and will take values that allow assessing the aptitude to the environment, then an initial population of random solutions. The "fittest" members of this initial population survive and continue to produce the next generation of solutions. The new solutions enter the population through a process of reproduction (in which the pairs of product lines "reproduce" to generate descendants that inherit each parent's attributes) and the mutation (in which the product lines undergo random changes in the individual characteristics of the product). This process continues until a certain detention condition is reached (Belloni et al., 2008). The genetic algorithms are expected to work well because they look for solutions from several alternatives in the solutions space, increasing the chances of finding good solutions.

There is an extensive literature that exposes applications based on genetic algorithms to solve PLD (Tsafarakis, 2010). Research in this field has had exponential growth in recent years and progressively in more diverse areas. In this bibliometric analysis, a broad analysis was carried out, to cover the largest number of variables that are related in this field of research, and to quantify the Journals that generate the greatest production, the authors with the greatest impact, the countries and the outstanding articles. A study with a bibliometric approach is a useful tool to quantitatively measure the bibliographic information that exists in a research field and how it expands into other areas.

However, despite being an expanding field there are few bibliometric works that relate both variables, an example is the work of (Zhong, RY, Dessouky, MI, Xu, 2018) that presents PDL and AG with a focus only on manufacturing, when work has also been done in different disciplines as mentioned above.

The aim of this article is to carry out an overview of PLD and GA variables which will be referred to as PDGA from now on, under a bibliometric analysis approach. The scope of the present work is to analyze the

evolution of this field from 1992 to 2018. With the objective of identifying the most relevant journals, authors, countries, institutions, and the different types of documents. A sample is created mainly with information from Scopus database. The results show that research in this area is growing and among the most notable journals are Computer Integrated Manufacturing Systems and the International Journal of Production Research. The most productive authors are Kwong, C.K. and Saitou, K. Among the leading countries in this field are China, the United States and Japan. The outstanding institutions are Hong Kong Polytechnic University, Shanghai Jiao Tong University and Zhejiang University.

The structure of the bibliometric analysis is as follows: in Section 2, the methodology is described in detail; in Section 3, an analysis of the variables using VOS Viewer software is presented, and lastly in Section 4 the relevant findings are presented, along with the conclusions.

2. METHODOLOGY

During the execution of this study, two databases, Web of Science (WoS) and Scopus, were used. It was observed that Scopus contained a higher number of documents related to the PDGA, so it was decided to unify the information in a single database with the purpose of making the study more comprehensive, leaving Scopus as the primary source of data. Both platforms were chosen because they have a good reputation as search tools and show relevant information about journals, authors, countries, institutions and documents (Blanco-Mesa, Fabio, León-Castro, Ernesto, Merigó, 2017).

The study begins by choosing the variables with which the search is to be conducted in order to delimit the areas of interest; in this case the topics were The Product Line Design Problem and Genetic Algorithms. The variable "The Product Line Design Problem" appears in the literature with different names such as "product development problem", "new product problem" and "product line problem", for this reason various keywords were used to perform a more complete search. The sample was taken on January 26, 2019, the keywords used were ("product development *") or ("new product *") or ("product line *") or ("product design *") and (" genetic algorithm * "), from 1992 to 2018. The number of documents obtained were 1,816, with a total of 20,310 citations, Table 1 shows the general information of each type of document.

TABLE 1. GENERAL INFORMATION OF DOCUMENT TYPES IN PDGA

Document types	Number	Total citations	% citations	% type document
Article	959	16,646	82%	52.81%
Article in press	4	4	0%	0.22%
Book	3	28	0%	0.17%
Book Chapter	21	31	0%	1.16%
Conference Paper	730	3,187	16%	40.20%
Conference Review	79	0	0%	4.35%
Editorial	3	23	0%	0.17%
Note	1	0	0%	0.06%
Report	1	1	0%	0.06%
Review	15	390	2%	0.83%
Total	1,816	20,310	100%	100%

Source: Own elaboration based on Scopus 2019.

The two main types of documents that make up the database are articles with 959 documents and conference papers with 730, despite having a similar volume, 86% of the total citations belong to articles and only 16% to conference papers. Table 2 shows the citation structure of articles and conference papers. Articles are the type of document that make the highest number of citations, in the range of 800-100 times. Most of the documents have been cited a few times in fact 8.32 % of the total publications make up the category of cited less than 25 times with a total of 1604. This amount is compounded by 49% as articles and 44% as conference papers. Another critical aspect to mention is the relevance of the PDGA research area over time. Figure 1 shows the growth over five periods, for each type of document: articles and conference papers.

TABLE 2. CITATION STRUCTURE

Number of citations	Number of documents	Article/ review	Conference paper	Article/ review (%)	Conference paper (%)
>800	1	1	0	100%	0%
200-800	1	1	0	100%	0%
100-200	31	30	1	97%	3%
50-100	58	51	7	88%	12%
25-50	121	102	19	84%	16%
0-25	1604	789	703	49%	44%
Total	1816	974	730	54%	40%

Source: Own elaboration based on Scopus and 2019

During the 1992-2004 period, the number of PDGA articles increased significantly from 176 articles published in the 4Q period to tripling, up to 526 publications, in the following period and until 2018, it has remained in an upward trend. 3Q period is the time in which most articles have been published and it represents 30% of the total data, followed by the 1Q period (2014-2018) with 505 publications that represent 29% of the items found.

FIG. 1. EVOLUTION OF THE NUMBER OF PUBLICATIONS ON PDGA

Source: Own elaboration

15
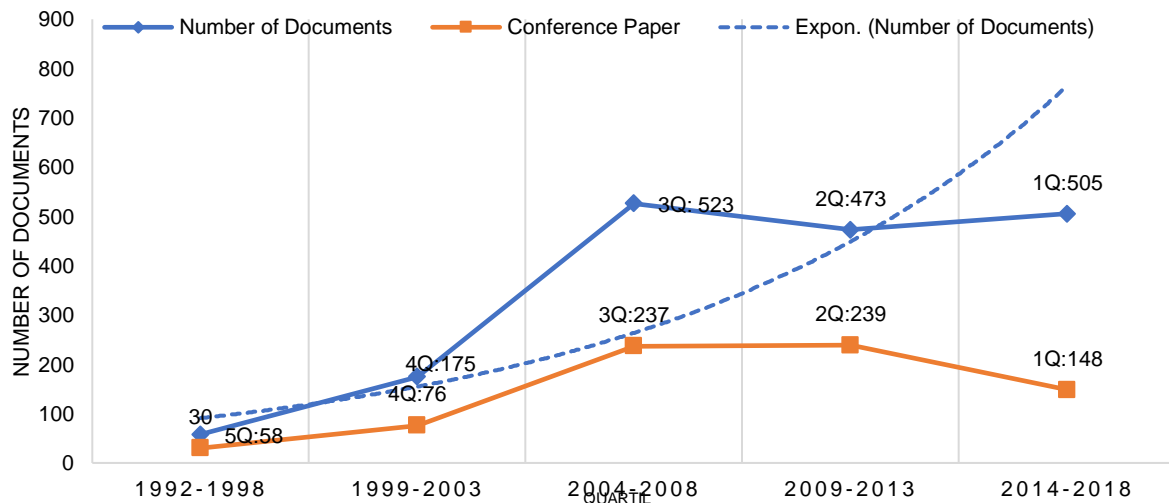
Regarding conference paper documents, 2Q is the period in which most publications were made with 239 documents (representing 33% of the total documents). However, during 1Q period (2014-2018), the works dropped to 148 documents, which represents 20% of the publications. Even so, the overall behavior of both types of documents shows exponential growth. An analysis of journals, articles, authors, institutions, and countries was carried out through different indicators such as productivity, total citations, and h-index. Productivity indicates the number of publications of magazines, authors, institutions or countries, and highlights which are the most important. The total citations indicate the number of citations obtained by the publication, and the h-index represents the importance of journals, authors, institutions or countries as it shows the relationship between the number of citations and the number of publications (Blanco-Mesa, León-Castro, Merigó, 2017).

3. RESULTS

3.1. The 30 most productive journals in Product Line Design Problem and Genetic Algorithms (PDGA)

Journals are the means of dissemination of contributions in the field of PDGA; Table 3 shows a list of the 30 journals with the highest production in PDGA; in this count, out of the 34 journals included, JJZX ranks first with 53 publications on PDGA. And although IJPR journal ranks second with 50 publications, it has the highest number of citations and h-index, with a total of 1252 and 21 correspondingly. The journal with the most significant presence in the count of the 30 most outstanding articles is EJOR with three publications. The journals with the

highest amount of production during the 1Q period are JJZX and IJAMT, with 18 documents each, and finally, it is essential to mention that the journal that presents the article with the most citations is IJIE. Considering all aspects in general, IJAMT with 48 documents, an h-index of 20, and 1248 citations, is not to be overlooked. In fact, two of its documents are among the 30 most essential works and produced 18 publications in the 1Q period.

3.2. The 30 most important papers and the 20 most notable conferences paper in PDGA

The importance of the documents found is described in this section, which are divided in two categories: articles and conferences papers, considering these are the two main types of publications, different in their attributes, that comprise the database. It is pertinent to identify the articles that have a high rate of citations, for that reason table 4 shows the ranking of the 30 documents with the highest number of citations, considering both Web of Science and Scopus databases. Among the most cited there is the work of (Nagamachi, 1995) with 892 citations, followed by (Ruiz & Maroto, 2006) with 274 citations, and the work of (Wu & Wan Tan, 2006) cited 188 times.

This ranking of 30 outstanding articles by citation is extracted from a compilation of 32 publications with a citation number higher than 100. The work of (Nagamachi, 1995) entitled: "Kansei Engineering: A new ergonomic consumer-oriented technology for product development" tops the ranking this study explains that the development of new products is oriented to consumer preferences,

TABLE 3. THE 30 MOST PRODUCTIVE JOURNALS IN PDGA

R	J	PPDGA	%PPDGA	hPDGA	TC	CS	CP	T30	≥800	≥200	≥100	≥50	≥25	1Q	2Q	3Q	4Q	5Q
1	JJZX	53	5.26%	8	202	0.84	26.2%	-	-	-	-	-	-	18	10	21	4	-
2	IJPR	50	4.97%	21	1252	4.34	4.0%	1	-	-	1	5	12	15	11	16	8	-
3	IJAMT	48	4.77%	20	1248	3.04	3.8%	2	-	-	2	6	8	18	12	14	4	-
4	CIE	27	2.68%	16	727	4.68	3.7%	1	-	-	1	5	3	11	9	4	1	2
5	EJOR	18	1.79%	12	1032	4.98	1.7%	3	-	1	2	6	2	5	2	8	3	-
6	JIM	17	1.69%	13	360	4.2	4.7%	-	-	-	-	1	4	5	6	3	2	1
7	JMD	15	1.49%	18	543	3.43	2.8%	2	-	-	2	1	1	1	4	7	3	-
8	ESA	15	1.49%	18	480	6.36	3.1%	1	-	-	1	2	2	2	11	2	-	-
9	ZJG	14	1.39%	3	35	0.38	40.0%	-	-	-	-	-	-	4	6	4	-	-
10	CERA	13	1.29%	7	372	1.79	3.5%	2	-	-	2		1	5	3	3	2	-
11	IJPE	12	1.19%	7	387	7.13	3.1%	1	-	-	1	1	2	6	-	6	-	-
12	JCP	10	0.99%	6	193	7.32	5.2%	-	-	-	-	1	2	9	1	-	-	-
13	AEI	10	0.99%	7	173	5.72	5.8%	-	-	-	-	1	-	5	2	1	2	
14	JGXC	10	0.99%	6	97	1.1	10.3%	-	-	-	-	1	3	3	2	5	-	-
15	JED	9	0.89%	4	69	2.7	13.0%	-	-	-	-	-	-	4	3	2	-	-
16	ASCJ	9	0.89%	5	182	6.27	4.9%	-	-	-	-	1	2	5	3	1	-	-
17	EAAI	8	0.79%	8	360	4.58	2.2%	1	-	-	1	1	2	2	-	5	-	1
18	PIME-B	7	0.70%	4	75	2.12	9.3%	-	-	-	-	-	1	2	1	3	1	-
19	MPIE	7	0.70%	3	18	1.13	38.9%	-	-	-	-	-	-	5	2	-	-	-
20	JFSYTX	7	0.70%	3	32	0.53	21.9%	-	-	-	-	-	-	1	2	3	1	-
21	IJCIM	7	0.70%	4	50	3.08	14.0%	-	-	-	-	-	-	4	1	2	-	-
22	IJIE	7	0.70%	7	1104	2.11	0.6%	2	1	-	1	1	2	1	2	2	-	2

R	J	PPDGA	%PPDGA	h-PDGA	TC	CS	CP	T30	≥800	≥200	≥100	≥50	≥25	1Q	2Q	3Q	4Q	5Q
23	NKGR	6	0.60%	1	7	0.103	85.7%	-	-	-	-	-	-	-	2	2	2	-
24	SMOP	6	0.60%	4	97	4.28	6.2%	-	-	-	-	-	1	2	3	1	-	-
25	PIM-C	6	0.60%	3	31	1.53	19.4%	-	-	-	-	-	-	6	-	-	-	-
26	AME	6	0.60%	2	13	1.24	46.2%	-	-	-	-	-	-	4	2	-	-	-
27	CIRPMT	6	0.60%	6	240	5.43	2.5%	1	-	-	1	-	3	1	1	2	-	2
28	CCE	6	0.60%	7	71	3.98	8.5%	-	-	-	-	-	-	3	1	1	-	1
29	DSS	5	0.50%	5	107	5.97	4.7%	-	-	-	-	-	2	1	-	1	1	2
30	JMSET	5	0.50%	4	60	3.22	8.3%	-	-	-	-	-	-	2	3	-	-	-
31	IEEEA	5	0.50%	3	14	4.96	35.7%	-	-	-	-	-	-	5	-	-	-	-
32	IJIETAP	5	0.50%	2	39	0.94	12.8%	-	-	-	-	-	1	1	-	1	3	-
33	KYJCD	5	0.50%	4	28	0.86	17.9%	-	-	-	-	-	-	-	3	2	-	-
34	CII	5	0.50%	5	178	6.05	2.8%	-	-	-	-	1	2	2	2	1	-	-

Source: Own elaboration based on Scopus 2019. R: Ranking; J: Journal; PPDGA: Total number of documents published in PDGA; %PPDGA: Percentage of articles published in PDGA; h-PDGA: h-index only with PDGA; TC: Total citations; CS: Impact factor; CP: Citations by paper; T30: Number of publications within the 30 most cited papers; ≥ 800: number of articles with more than 800 citations; ≥ 200: number of articles with more than 200 citations; ≥100: number of articles with more than 100 citations; ≥50: number of articles with more than 50 citations; ≥25: number of articles with more than 25 citations; 1Q: 2014-2018; 2Q: 2009-2013; 3Q: 2004-2008; 4Q: 1999-2003; 5Q: 1992-1998. Journal abbreviations are: JJZX: Jisuanji Jicheng Zhizao Xitong/Computer Integrated Manufacturing Systems, CIMS; IJPR: International Journal of Production Research; IJAMT: International Journal of Advanced Manufacturing Technology; CIE: Computers and Industrial Engineering; EJOR: European Journal of Operational Research; JIM: Journal of Intelligent Manufacturing; JMD: Journal of Mechanical Design, Transactions of the ASME; ESA: Expert Systems with Applications; ZJG: Zhongguo Jixie Gongcheng/China Mechanical Engineering; CERA: Concurrent Engineering Research and Applications; IJPE: International Journal of Production Economics; JCP: Journal of Cleaner Production; AEI: Advanced Engineering Informatics; JGXC: Jixie Gongcheng Xuebao/Chinese Journal of Mechanical Engineering; JED: Journal of Engineering Design; ASCJ: Applied Soft Computing Journal; EAAI: Engineering Applications of Artificial Intelligence; PIME-B: Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture; MPIE: Mathematical Problems in Engineering; JFSYTX: Jisuanji Fuzhu Sheji Yu Tuxingxue Xuebao/Journal of Computer-Aided Design and Computer Graphics; IJCIM: International Journal of Computer Integrated Manufacturing; IJIE: International Journal of Industrial Ergonomics; NKGR: Nihon Kikai Gakkai Ronbunshu, C Hen/Transactions of the Japan Society of Mechanical Engineers, Part C; SMOP: Structural and Multidisciplinary Optimization; PIM-C: Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science; AME: Advances in Mechanical Engineering; CIRPMT: CIRP Annals - Manufacturing Technology; CCE: Computers and Chemical Engineering; DSS: Decision Support Systems; JMSET: Journal of Manufacturing Science and Engineering, Transactions of the ASME; IEEEA: IEEE Access; IJIETAP: International Journal of Industrial Engineering : Theory Applications and Practice; KYJCD: Kongzhi yu Juece/Control and Decision; CII: Computers in Industry.

Table 4. Top 30 most essential documents from Scopus and WoS.

R	Authors	Title	Year	Source title	TC	DT	DB
1	Nagamachi M.	Kansei Engineering: A new ergonomic consumer-oriented technology for product development	1995	International Journal of Industrial Ergonomics	822	A	Scopus
2	Ruiz R., Maroto C.	A genetic algorithm for hybrid flowshops with sequence dependent setup times and machine eligibility	2006	European Journal of Operational Research	274	A	Scopus
3	Wu Dongrui, Wan Tan Woei	Genetic learning and performance evaluation of interval type-2 fuzzy logic controllers	2006	Engineering Applications of Artificial Intelligence	188	A	Scopus
4	Choudhary, AK; Harding, JA; Tiwari, MK	Data mining in manufacturing: a review based on the kind of knowledge	2009	Journal of Intelligent Manufacturing	188	R	WOS
5	Huang G.Q., Zhang X.Y., Liang L.	Towards integrated optimal configuration of platform products, manufacturing processes, and supply chains	2005	Journal of Operations Management	181	A	Scopus
6	Thomas L., Larroche C., Pandey A.	Current developments in solid-state fermentation	2013	Biochemical Engineering Journal	170	R	Scopus
7	Min H., Ko H.-J.	The dynamic design of a reverse logistics network from the perspective of third-party logistics service providers	2008	International Journal of Production Economics	170	A	Scopus
8	Zeng M., Li J., Peng Z.	The design of Top-Hat morphological filter and application to infrared target detection	2006	Infrared Physics and Technology	162	A	Scopus
9	Li H., Azarm S.	An approach for product line design selection under uncertainty and competition	2002	Journal of Mechanical Design, Transactions of the ASME	161	A	Scopus
10	Yildiz A.R.	A novel particle swarm optimization approach for product design and manufacturing	2009	International Journal of Advanced Manufacturing Technology	160	A	Scopus
11	Kim Y.K., Kim Y., Kim Y.J.	Two-sided assembly line balancing: A genetic algorithm approach	2000	Production Planning and Control	158	A	Scopus
12	Wang J., Shu Y.-F.	Fuzzy decision modeling for supply chain management	2005	Fuzzy Sets and Systems	150	A	Scopus
13	Zhou C.-C., Yin G.-F., Hu X.-B.	Multi-objective optimization of material selection for sustainable products: Artificial neural networks and genetic algorithm approach	2009	Materials and Design	144	A	Scopus
14	Tseng H.-E., Chang C.-C., Li J.-D.	Modular design to support green life-cycle engineering	2008	Expert Systems with Applications	139	A	Scopus
15	López-Ibáñez M., Prasad T.D., Paechter B.	Ant colony optimization for optimal control of pumps in water distribution networks	2008	Journal of Water Resources Planning and Management	137	A	Scopus
16	Blau G.E., Pekny J.F., Varma V.A., Bunch P.R.	Managing a portfolio of interdependent new product candidates in the pharmaceutical industry	2004	Journal of Product Innovation Management	136	A	Scopus
17	Wu X., Chu C.-H., Wang Y., Yan W.	A genetic algorithm for cellular manufacturing design and layout	2007	European Journal of Operational Research	129	A	Scopus

18	Balakrishnan P.V., Jacob V.S.	Genetic algorithms for product design	1996	Management Science	129	A	Scopus
19	Wu, C; Barnes, D	A literature review of decision-making models and approaches for partner selection in agile supply chains	2011	Journal of Purchasing and Supply Management	127	R	WOS
20	Simaria A.S., Vilarinho P.M.	A genetic algorithm based approach to the mixed-model assembly line balancing problem of type II	2004	Computers and Industrial Engineering	127	A	Scopus
21	Hsiao S.-W., Tsai H.-C.	Applying a hybrid approach based on fuzzy neural network and genetic algorithm to product form design	2005	International Journal of Industrial Ergonomics	123	A	Scopus
22	Reca J., Martínez J.	Genetic algorithms for the design of looped irrigation water distribution networks	2006	Water Resources Research	122	A	Scopus
23	Simpson T.W., D'Souza B.S.	Assessing variable levels of platform commonality within a product family using a multiobjective genetic algorithm	2004	Concurrent Engineering Research and Applications	121	A	Scopus
24	Fung R.Y.K., Tu Y., Tang J., Wang D.	Product design resources optimization using a non-linear fuzzy quality function deployment model	2002	International Journal of Production Research	115	A	Scopus
25	Hung S.L., Adeli H.	A Parallel Genetic/Neural Network Learning Algorithm for MIMD Shared Memory Machines	1994	IEEE Transactions on Neural Networks	113	A	Scopus
26	Yu, TL; Yassine, AA; Goldberg, DE	An information theoretic method for developing modular architectures using genetic algorithms	2007	Research In Engineering Design	112	A	WOS
27	Viennet R., Fonteix C., Marc I.	Multicriteria optimization using a genetic algorithm for determining a Pareto set	1996	International Journal of Systems Science	112	A	Scopus
28	Rashid M.F.F., Hutabarat W., Tiwari A.	A review on assembly sequence planning and assembly line balancing optimisation using soft computing approaches	2012	International Journal of Advanced Manufacturing Technology	111	R	Scopus
29	Jiao J., Zhang Y.	Product portfolio planning with customer-engineering interaction	2005	IIE Transactions (Institute of Industrial Engineers)	109	A	Scopus
30	Gu P., Hashemian M., Sosale S.	An integrated modular design methodology for life-cycle engineering	1997	CIRP Annals - Manufacturing Technology	105	A	Scopus
31	Kameyama M., Fukunaga H.	Optimum design of composite plate wings for aeroelastic characteristics using lamination parameters	2007	Computers and Structures	103	A	Scopus
32	Li M., Li G., Azarm S.	A kriging metamodel assisted multi-objective genetic algorithm for design optimization	2008	Journal of Mechanical Design, Transactions of the ASME	102	A	Scopus

Source: Own elaboration based on Scopus and WoS 2019. TC: total citation; DT: document type; DB:data base.

current computer technologies, like the expert system, the neural network model and the genetic algorithm, are used as part of the methodology.The cited work of (Wu & Wan Tan, 2006) presents parameter settings through fuzzy logic and genetic algorithms. The studies show that the field and research of PDGA can have many applications in different areas, this allows the identification of gaps that can be the guidelines for future research.

Table 5 shows the most important conference papers; the ranking is made up of Scopus and WoS documents in order to have a complete database, with the former as its primary source. The conference paper "PLANTS: Application of ant colony optimization to structure-based drug design"

by (Korb, Stützle, & Exner, 2006) is the work with the highest number of citations at 132

times, it is about drug design through genetic algorithms.

TABLE 5. THE 30 MOST NOTABLE CONFERENCES PAPERS ON PDGA

R	Title	Authors	Journal	TC	Data Base
1	PLANTS: Application of ant colony optimization to structure-based drug design	Korb O., Stützle T., Exner T.E.	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	132	Scopus
2	Search Based Software Engineering for software product line engineering: A survey and directions for future work	Harman M., Jia Y., Krinke J., Langdon W.B., Petke J., Zhang Y.	ACM International Conference Proceeding Series	78	Scopus
3	A template for scatter search and path relinking	Glover, F	Artificial Evolution	77	WOS
4	Minimizing test suites in software product lines using weight-based genetic algorithms	Wang S., Ali S., Gotlieb A.	GECCO 2013 - Proceedings of the 2013 Genetic and Evolutionary Computation Conference	68	Scopus
5	A genetic algorithm for developing modular product architectures	Yu T.-L, Yassine A.A., Goldberg D.E.	Proceedings of the ASME Design Engineering Technical Conference	66	Scopus
6	Optimal design of magnetically actuated optical image stabilizer mechanism for cameras in mobile phones via genetic algorithm	Chiu C.-W., Chao P.C.-P., Wu D.-Y.	IEEE Transactions on Magnetics	61	Scopus
7	Multi-objective test generation for software product lines	Henard C., Papadakis M., Perrouin G., Klein J., Le Traon Y.	ACM International Conference Proceeding Series	60	Scopus
8	A genetic algorithm for solving economic lot size scheduling problem	Sarker R., Newton C.	Computers and Industrial Engineering	55	Scopus
9	Product variety optimization: Simultaneous optimization of module combination and module attributes	Fujita K., Yoshida H.	Proceedings of the ASME Design Engineering Technical Conference	50	Scopus
10	A phonon scattering assisted injection and extraction-based terahertz quantum cascade laser	Dupont E., Fathololoumi S., Wasilewski Z.R., Aers G., Laframboise S.R., Lindskog M., Razavipour S.G., Wacker A., Ban D., Liu H.C.	Journal of Applied Physics	48	Scopus
11	A new integrated design method based on fuzzy matter-element optimization	Zhao Y.W., Zhang G.X.	Journal of Materials Processing Technology	47	Scopus
12	Evolutionary search-based test generation for software product line feature models	Ensan F., Bagheri E., Gašević D.	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	46	Scopus
13	Automated design synthesis for Micro-Electro-Mechanical Systems (MEMS)	Zhou N., Agogino A., Pister K.S.J.	Proceedings of the ASME Design Engineering Technical Conference	43	Scopus

14	A novel algorithm for multimodal function optimization based on evolution strategy	Im C.-H., Kim H.-K., Jung H.-K., Choi K.	IEEE Transactions on Magnetics	42	Scopus
15	Evolutionary computing for optimizing type-2 fuzzy systems in intelligent control of non-linear dynamic plants	Castillo O., Huesca G., Valdez F.	Annual Conference of the North American Fuzzy Information Processing Society - NAFIPS	41	Scopus
16	Genetic algorithms as an approach to configuration and topology design	Chapman Colin D., Saitou Kazuhiro, Jakiela Mark J.	American Society of Mechanical Engineers, Design Engineering Division (Publication) DE	35	Scopus
17	Genetic approach to the cable harness routing problem	Conru Andrew B.	IEEE Conference on Evolutionary Computation - Proceedings	35	Scopus
18	Assessing variable levels of platform commonality within a product family using a multi objective genetic algorithm	Simpson T.W., D'Souza B.	9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization	35	Scopus
19	Multi-objective design optimization for product platform and product family design using genetic algorithms	Akundi S.V.K., Simpson T.W., Reed P.M.	Proceedings of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference - DETC2005	35	Scopus
20	Cost-effective test suite minimization in product lines using search techniques	Wang S., Ali S., Gotlieb A.	Journal of Systems and Software	34	Scopus

Source: Own elaboration based on Scopus 2019. R: Ranking; TC: Total Citation

3.3. Foremost 30 authors on PDGA

Identifying the author, is one of the first impressions that can be had about an article even before reading it. The ideas and styles of the authors significantly contribute to the enrichment of research areas; such is the case in PDGA. For this reason, a computation was made on the most outstanding authors in that area. Table 6 shows the 30 foremost authors based on a production greater than 6 publications. In the first position there is Kwong C. K with a PPDGA of 26 and has been cited 408 times, he also has an h-PDGA of 13 which is the highest in the list, finally it is noteworthy how 14 of his publications take place during 1Q time. Although Nagamachi has a PPDGA of only 6, he is the most cited author on the list. Just as important is the author Azarn S. who has the highest average citations per article with 56.57 and is also the one with the most works present within 30 most relevant articles, with two works. Additionally, it is observed that a significant number of authors within the first 10 positions in the ranking are still interested in publishing about PDGA, since most of their production has been done during the time periods 1Q and 2Q, as in the case of Du, G. who has a PPDGA of 13 which was produced entirely in the 1Q period, it can be deduced that this is an author who in the near future will have high production.

TABLE 6. FOREMOST 30 AUTHORS IN PDGA

R	Author	C	PPDGA	%	hPDGA	T.C	CP	T30	1Q	2Q	3Q	4Q	5Q
1	Kwong, C.K.	HKN	26	1.43%	13	408	15.69	-	14	11	-	1	-
2	Saitou, K.	USA	22	1.21%	7	245	11.14	-	-	-	12	9	1
3	Tang, J.F.	NZL	14	0.77%	9	332	23.71	1	4	7	2	1	-
4	Luo, X.G.	CHN	14	0.77%	7	146	10.43	-	4	9	1	-	-
5	Jiao, R.J.	SGP	13	0.72%	7	181	13.92	-	9	2	2	-	-
6	Du, G.	CHN	13	0.72%	4	110	8.46	-	13	-	-	-	-
7	Yang, Y.	CHN	11	0.61%	5	51	4.64	-	8	2	1	-	-
8	Simpson, T.W.	USA	11	0.61%	7	313	28.45	1	2	1	6	2	
9	Liu, X.	CHN	11	0.61%	4	46	4.18	-	-	10	1	-	-
10	Dou, R.	CHN	10	0.55%	4	66	6.60	-	9	1	-	-	-
11	Yoshimura, M.	JAP	9	0.50%	3	60	6.67	-	-	-	3	5	1
12	Izui, K.	JAP	9	0.50%	3	60	6.67	-	-	-	3	5	1
13	Fujita, K.	JAP	9	0.50%	5	206	22.89	1	1	3	2	3	-
14	Poirson, E.	FRA	8	0.44%	3	51	6.38	-		6	2	-	-
15	Pibouleau, L.	FRA	8	0.44%	3	38	4.75	-	1	3	4	-	-
16	Bercsey, T.	HUN	8	0.44%	2	8	1.00	-	-	-	6	1	1
17	Azzaro-Pantel, C.	FRA	8	0.44%	3	37	4.63	-	2	2	4	-	-
18	Sun, S.	CHN	8	0.44%	4	65	8.13	-	1	3	4	-	-
19	Huang, G.Q.	HKN	8	0.44%	6	313	39.13	1	-	2	5	1	-
20	Xue, D.	CAN	7	0.39%	2	24	3.43	-	2	2	2	1	-
21	Tseng, H.E.	TWN	7	0.39%	6	285	40.71	1	1	2	4	-	-
22	Gao, L.	CHN	7	0.39%	3	66	9.43	-	1	6	-	-	-
23	Fu, Y.	USA	7	0.39%	2	14	2.00	-	-	1	6	-	-
24	Feng, Y.X.	CHN	7	0.39%	3	40	5.71	-	3	2	2	-	-
25	Bennis, F.	FRA	7	0.39%	3	23	3.29	-	-	5	1	1	-
26	Azarm, S.	USA	7	0.39%	7	396	56.57	2	-	1	3	3	-
27	Wang, L.	CHN	7	0.39%	5	69	9.86	-	2	2	3	-	-
28	Nagamachi, M.	JAP	6	0.33%	4	884	147.33	1	-	-	-	3	3
29	Hsiao, S.W.	TWN	6	0.33%	5	231	38.50	1	1	2	3	-	-
30	Tsai, H.C.	TWN	6	0.33%	4	194	32.33	1	-	2	4	-	-

Source: Own elaboration based on Scopus 2019; R: Ranking; C: Country; PPDGA: Total number of documents published in PPDGA; %PPDGA: Percentage of articles published in PDGA; hPDGA: H-index only with PDGA; TC: Total citations; CP: Citations by paper; T30: Number of publications within the 30 most cited papers; 1Q: 2014-2018; 2Q: 2009-2013; 3Q: 2004-2008; 4Q: 1999-2003; 5Q: 1992-1998

3.4. The 30 most Influential Institutions in PDGA

In this section, the most representative Institutions and Universities in the PDGA research field were reviewed. Table 7 shows a list of the 30 most notable institutions, in which the Hong Kong Polytechnic University with its high scores on PPDGA at 43, h-PDGA at 17 and TC at 651 assumes the first position. The institution with the highest average of mentions is Feng Chia University of Taiwan, with a CP of 32.55.

Another important indicator is the period in which the publications are made, where Tianjin University stands out with 24 publications in 1Q, Hong Kong Polytechnic University with 17 publications in 1Q and 2Q, also Beihang University with is most significant production of 12 articles, made in 1Q representing 52.17% of all its publications. It is also important to mention that the Shanghai Jiao Tong University and the Feng Chia University are the two institutions that produced 2 documents ranking among the most relevant.

TABLE 7. THE 30 MOST INFLUENTIAL INSTITUTIONS IN PDGA

R	Institution	C	PPDGA	%	h-PDGA	TC	CP	T30	1Q	2Q	3Q	4Q	5Q
1	Hong Kong Polytechnic University	HKG	43	2.37%	17	651	15.14	-	17	17	6	3	-
2	Shanghai Jiao Tong University	CHN	40	2.20%	12	609	15.23	2	9	12	18	1	-
3	Zhejiang University	CHN	36	1.98%	10	264	7.33	-	13	12	10	1	-
4	Northeastern University China	CHN	34	1.87%	10	411	12.09	1	13	13	4	4	-
5	University of Michigan, Ann Arbor	USA	33	1.82%	11	489	14.82	1	-	6	17	10	-
6	Tianjin University	CHN	32	1.76%	7	192	6.00	-	24	5	2	1	-
7	Huazhong University of Science and Technology	CHN	30	1.65%	9	317	10.57	-	2	16	8	3	1
8	Chongqing University	CHN	26	1.43%	7	98	3.77	-	11	13	2	-	-
9	Beihang University	CHN	23	1.27%	7	235	10.22	-	12	5	6	-	-
10	Pennsylvania State University	USA	22	1.21%	9	350	15.91	1	4	2	11	3	2
11	Nanjing University of Aeronautics and Astronautics	CHN	21	1.16%	5	106	5.05	-	7	8	5	1	
12	Tsinghua University	CHN	21	1.16%	7	182	8.67	-	3	1	9	7	1
13	Zhejiang University of Technology	CHN	21	1.16%	6	122	5.81	-	-	13	6	2	-
14	Nanyang Technological University	SGP	20	1.10%	13	522	26.10	1	6	2	10	2	-
15	Ministry of Education China	CHN	19	1.05%	6	142	7.47	-	6	12	1		-
16	Northwestern Polytechnical University	CHN	19	1.05%	3	49	2.58	-	6	5	7	1	-
17	National Cheng Kung University	TWN	19	1.05%	9	457	24.05	1	5	4	9	1	-
18	Shanghai University	CHN	18	0.99%	6	141	7.83	-	4	3	9	2	-
19	Xi'an Jiaotong University	CHN	16	0.88%	5	112	7.00	-	4	3	9	-	-
20	Georgia Institute of Technology	USA	16	0.88%	7	234	14.63	-	11	3	1	-	1
21	Dalian University of Technology	CHN	15	0.83%	5	107	7.13	-	4	5	6	-	-
22	National University of Singapore	SGP	14	0.77%	7	343	24.50	1	4	2	7	1	-
23	University of Calgary	CAN	13	0.72%	5	42	3.23	-	5	3	4	1	-
24	The University of Hong Kong	HKG	13	0.72%	8	345	26.54	1	2	2	8	1	-
25	Laboratoire des Sciences du Numérique de Nantes	FRA	13	0.72%	5	75	5.77	-	1	9	3	-	-
26	University of Tehran	IRN	12	0.66%	6	199	16.58	-	5	5	2	-	-
27	Feng Chia University	TWN	11	0.61%	6	358	32.55	2	1	1	9	-	-
28	Kyoto University	JAP	11	0.61%	4	70	6.36	-	2	3	-	5	1
29	Iran University of Science and Technology	IRN	11	0.61%	5	79	7.18	-	5	4	2	-	-
30	The George W. Woodruff School of Mechanical Engineering	USA	11	0.61%	7	220	20.00	-	7	3	1	-	-

3.5. The 30 most notable countries in PDGA

The development of science and technology are the means through which countries progress; therefore, it is vital to analyze the level of scientific production in a country. Particularly, in the field of PDGA there are outstanding countries, shown the 30 most outstanding in table 8. In this count,

China is the country that has the highest production in PDGA with 572 publications, it holds a total of 4,032 citations and it is the country that has the highest production in the 1Q time with 201 documents and 198 articles in 2Q. The country with the highest TC is the United States of America with 5,393; it has also placed eight documents in the ranking of the most outstanding articles

TABLE 8. THE 30 MOST NOTABLE COUNTRIES IN PDGA

R	C	PPDGA	%PPDGA	h-PDGA	TC	CP	T30	1Q	2Q	3Q	4Q	5Q
1	CHN	572	31.50%	29	4032	7.05	6	201	198	140	29	4
2	USA	348	19.16%	37	5393	15.50	8	62	73	124	64	25
3	JAP	110	6.06%	14	1605	14.59	3	22	26	28	25	9
4	TWN	109	6.00%	25	2169	19.90	5	18	31	51	8	1
5	IND	81	4.46%	19	1133	13.99	1	29	28	18	6	-
6	UK	76	4.19%	18	1029	13.54	2	20	19	18	10	9
7	HKG	65	3.58%	21	1401	21.55	2	20	21	17	7	-
8	FRA	57	3.14%	14	708	12.42	2	19	20	13	3	2
9	IRN	56	3.08%	16	670	11.96	-	32	15	9	-	-
10	CAN	50	2.75%	14	649	12.98	1	11	12	21	3	3
11	SGP	39	2.15%	17	997	25.56	3	11	4	21	3	-
12	DEU	38	2.09%	8	428	11.26	-	11	9	13	4	1
13	KOR	38	2.09%	13	747	19.66	2	8	8	18	4	-
14	ESP	38	2.09%	12	740	19.47	2	15	6	16	1	-
15	AUS	28	1.54%	10	281	10.04	-	12	9	4	3	-
16	ITA	27	1.49%	9	286	10.59	-	10	4	9	4	-
17	TUR	20	1.10%	9	517	25.85	1	8	3	9	-	-
18	NOR	19	1.05%	7	181	9.53	-	13	1	5	-	-
19	MEX	16	0.88%	5	152	9.50	-	3	6	6	-	1
20	BRA	15	0.83%	5	61	4.07	-	11	1	2	1	-
21	GRC	15	0.83%	6	136	9.07	-	7	4	2	2	-
22	NLD	15	0.83%	4	58	3.87	-	2	3	7	1	2
23	MYS	13	0.72%	7	163	12.54	-	7	3	3	-	-
24	SWE	12	0.66%	5	102	8.50	-	1	8	-	3	-
25	HUN	11	0.61%	3	18	1.64	-	2	1	7	1	-
26	PRT	10	0.55%	5	209	20.90	1	6	1	3	-	-
27	THA	10	0.55%	3	80	8.00	-	4	2	3	1	-
28	ISR	9	0.50%	5	133	14.78	-	2	2	3	2	-
29	PAK	9	0.50%	3	76	8.44	-	5	2	2	-	-
30	EGY	8	0.44%	2	50	6.25	-	4	2	1	1	-

4. VISUALITATION USING VOS VIEWER

In this section, the VOS viewer graphic tool was used to represent a bibliographic analysis of PDGA in the form of a graphic organizer. The software allows analysis such as co-citation, co-occurrence of author keywords, and bibliographic coupling.

The co-citation in bibliometric studies is used when a document cites two others, showing the probability in content association that both sources cited, the co-occurrence of author keywords identifies the most common keywords that appear most frequently in the documents and the bibliographic coupling happens when two documents cite the same third document (Blanco-Mesa, León-Castro, Merigó, 2017).

FIGURE 2. CO-CITATIONS OF JOURNALS AMONG PDGA PUBLICATIONS.
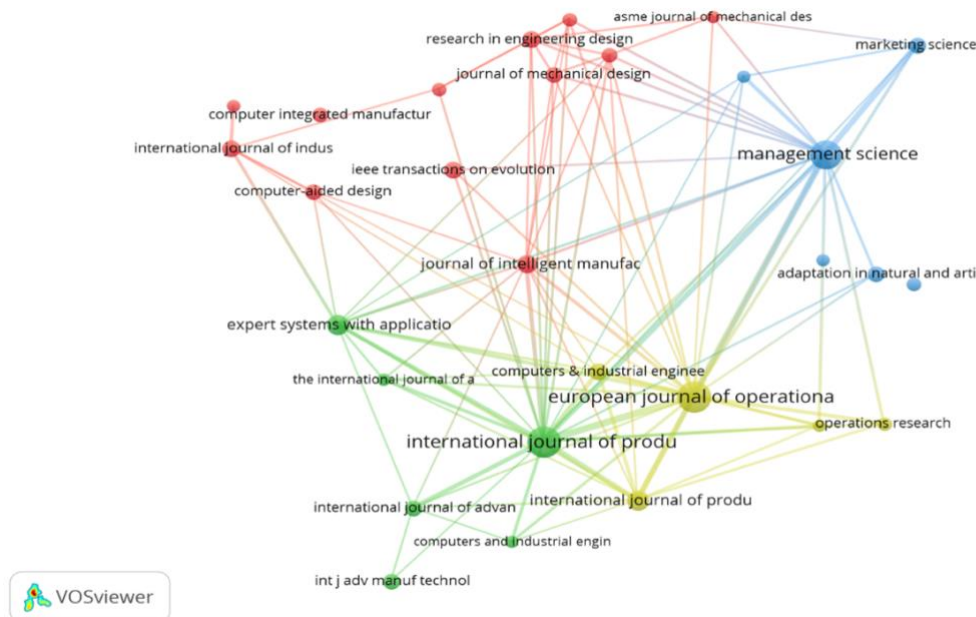
Source: Own elaboration based on Scopus 2019.

Specifically, an analysis of co-citation of Journals among PDGA publications, shown in Figure 2, was made in order to present the most cited Journals. To draw the figure, we considered the journal with 100 most active co-citations links and a minimum threshold of 100 citations, the results indicate that the International Journal of Production Research and European Journal of Operational Research are the most outstanding journals. The main issues of journals are administrative sciences, operations research, manufacturing systems, and computing.

The graphical result of the Co-citation of authors among PDGA publications analysis is presented in Figure 3. Parameters considered are 200 active co-citations links and a minimum threshold of 50 citations. Thus, it is observed that the most outstanding authors are Simpson TW and Dev K., despite their absence in the ranking of the 30 most essential authors, their work is widely cited.

FIGURE 3. CO-CITATION OF AUTHORS AMONG PDGA PUBLICATIONS.
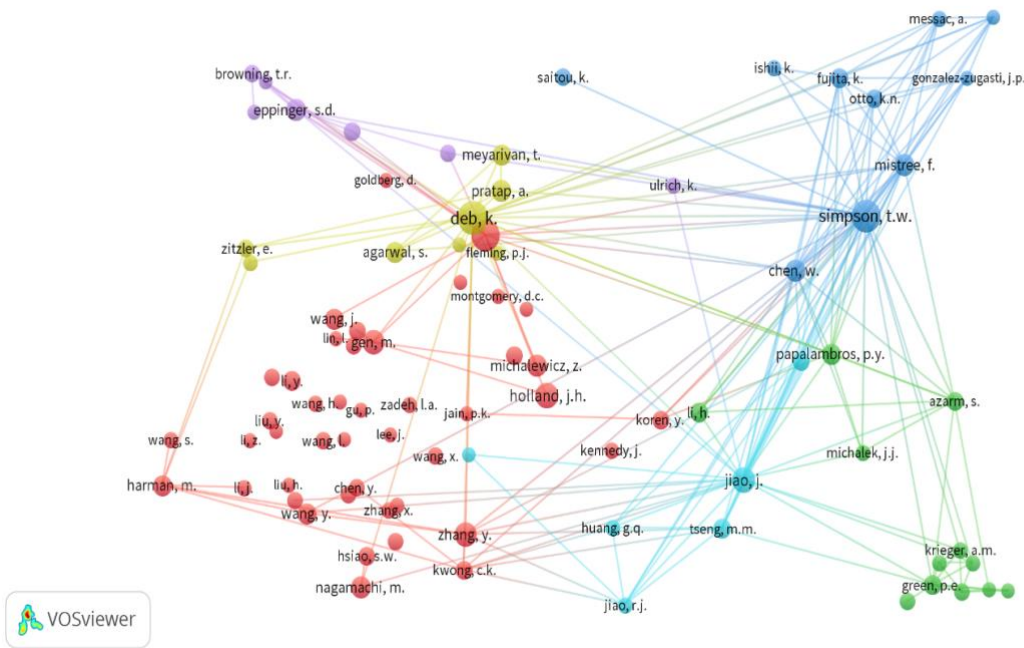
Source: Own elaboration based on Scopus 2019.

Four types of bibliographic coupling analysis were performed, the first one shown in Figure 4 called bibliographic coupling of journals in PDGA publications where the leading journals regarding documents are shown; the requirements were to be on the one hundred most active bibliographic coupling connections and a minimum threshold of 5 publications. The proceedings of the ASME Design engineering make it the recipient of the most significant publications.

A bibliographic coupling of authors maps shows the most productive authors in PDGA, and those that more frequently cite the same documents. Figure 5 shows the analysis based on 50 most active bibliographic coupling connections and a threshold of 3 papers, in which authors Kwong C.K. and Balakrishna are in this figure. However, the former is also the most outstanding in the ranking of the 30 most essential authors in PDGA, but the latter outstands for being the first author to use genetic algorithms to solve the problem of product design. Within the same group, names such as Wang J. and Saitou K. also appear, these authors used GA to address multiple attribute configuration problems. Although Saitou K.'s works are not in the top 30 of the most cited documents, in the aforementioned figure it is shown that his work is of great influence for other authors.

Source: Own elaboration based on Scopus 2019.

Concerning the results on the bibliographic coupling of countries, considering the 50 most active bibliographic coupling lin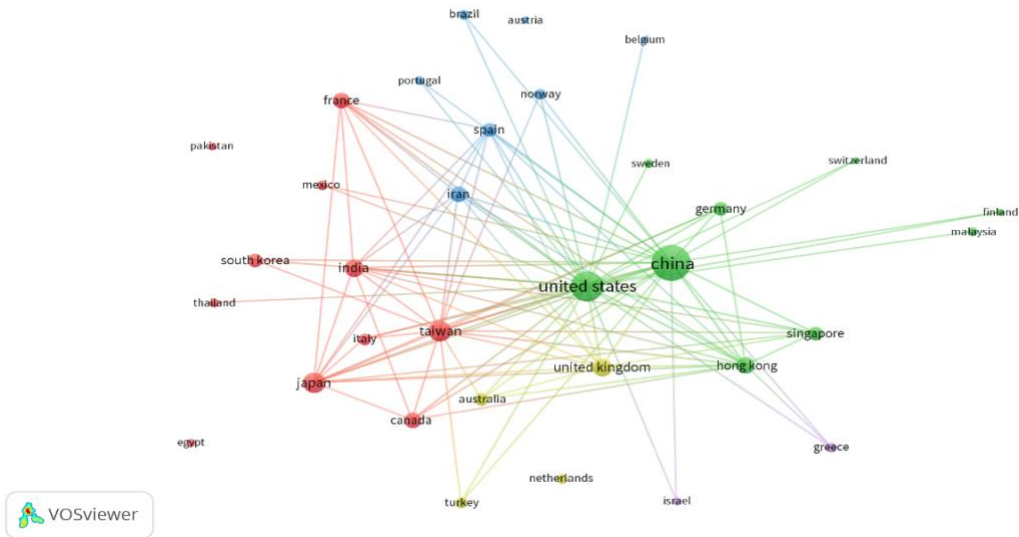ks and a minimum threshold of 5 publications. China and the USA are the countries with the highest production in PDGA, as shown in Figure 6.

FIGURE 5. BIBLIOGRAPHIC COUPLING OF AUTHORS IN PDGA PUBLICATIONS.
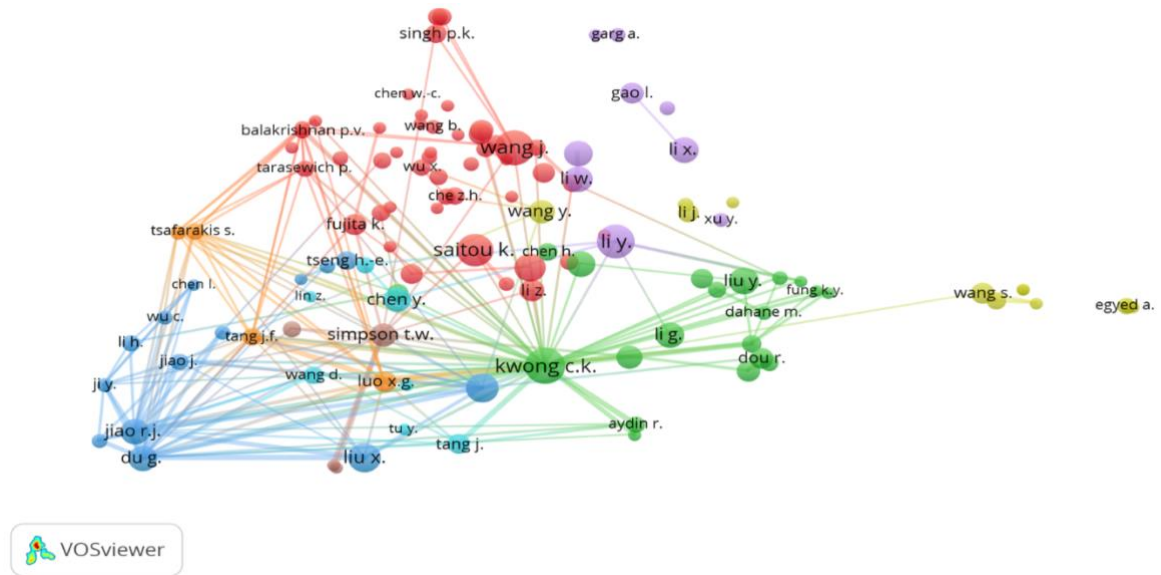
Source: Own elaboration based on Scopus 2019.

FIGURE 6. BIBLIOGRAPHIC COUPLING OF COUNTRIES IN PDGA PUBLICATIONS.

Source: Own elaboration based on Scopus 2019.

Finally, a map presenting the most common keywords in PDGA is shown, Figure 7 reveals the co-occurrence of author keywords among PDGA publications. The map is made with one hundred most active co-occurrence links and a minimum threshold of 10 occurrences. The most frequently mentioned words in the documents are genetic algorithms, optimization, and product design. Other words are mentioned depending on the area of research, which shows that there is a wide variety of applications for PDGA.

FIG. 7. CO-OCURRENCE AUTHOR KEYWORDS AMONG PDGA PUBLICATIONS.

Source: Own elaboration based on Scopus 2019.

Romero-Serrano, A. M., Ahumada-Valenzuela, O., Leyva-Lopez, J. C., and Velazquez-Cazares, M. G.
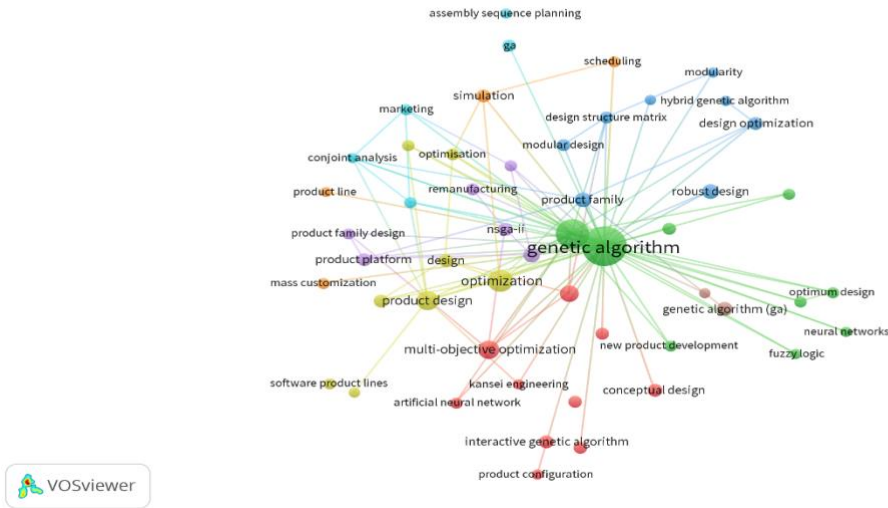
Keywords such as product family design, product family and product line appear in different clusters, which indicates a trend to develop product lines that offer a product with distinct configurations. The figure

5. CONCLUSION

This study presents a review of the product line design problem from 1992 to 2018, using information from Scopus as the primary source and complementing with Web of Science Data Base, with a sample of 1,816 documents. It is essential to mention that the production tripled from the year 2004 and has been constant during the 2014-2018 period, which represents 30% of the total production; this leads to conclude that the research area is an issue of current importance. The analysis of journals reveals that the leaders publish PDGA in the fields of Computer Integrated Manufacturing Systems with a production of 53 documents, followed by the International Journal of Production Research with a production of 50 documents and the International Journal of Advanced Manufacturing Technology with a 48 documents production.

The two main types of documents that make up the database are articles (49%) and conference papers (44%). The most cited document is "Kansei Engineering: A new ergonomic consumer-oriented technology for product development", published by Nagamachi in 1995, with 822 citations.

In the 2014-2018 time period, relevant works are found, such as (Hartmann, Van Der Linden and Bosch, 2014), entitled *"Search-based software engineering for software product line engineering: a survey and directions for future work"*. This is the most cited article in the 5Q period with 78 citations and discusses the advances in the use

shows that optimization methods emerge in diverse areas, as a crucial issue in PLD, as much as quality, marketing, and manufacturing are.

of genetic programming in the development of software, with the purpose of finding solutions in challenging problems on the topic product line development.

Among the most recent notable works is that of (Lee, 2018), which is a review on the literature of works published between 2007-2017, it methodologically analyzes the applications of GA in operations research, and the main areas of application were design of products, control and improvement of operations. Despite the existence of a broad application, the results of this review pave the way for future research to apply GA to solve operations research problems.

The most notable authors come from China, Japan, and the USA, when it comes to the ten most essential institutions, 8 come from China, and 2 belong to the USA. The countries with the highest production of the product line design problem are China, the USA, Japan, and Taiwan. The maps made show us the interrelations so far presented within the PDGA research field and various areas such as engineering, mass customization, product line software, and optimization.

In future studies, it is proposed to address issues related to the choice model, support for consumer decision making and other specific methods that integrate consumer preferences during the early design stages.

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