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Contributions to the future of metaheuristics in the contours of scientific development

Contribuições para o futuro da metaheurística nos contornos do desenvolvimento científico

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Abstract: Metaheuristic algorithms solve optimisation problems by identifying the best combination among a set of variables to enhance a function. Within metaheuristics, the main purpose of this work is that of showing the development of research issues about processes related to optimisation and metaheuristics, with a focus on the projection of those issues with greater possibility of development. Optimization processes is one of the most studied fields in artificial intelligence, optimization, logistics, and other applications The main contributions of this work were the identification of the main issues contained in the themes of process optimization and metaheuristics; an analysis of the expansion and retraction of the aforementioned theme; an understanding of convergence and divergence; and an analysis of the stages of development as presented in the gaps of the fifty most commonly mentioned articles. The main finding was to analyze the development of research topics on optimization processes and metaheuristics, focusing on projecting the topics most likely to develop.

Keywords: Optimization; Modelling; Algorithm; Metaheuristics.

Resumo: Os algoritmos meta-heurísticos resolvem problemas de optimização identificando a melhor combinação entre um conjunto de variáveis para melhorar uma função. Dentro da meta-heurística, o principal objetivo deste trabalho é mostrar o desenvolvimento de questões de investigação sobre processos relacionados com a optimização e a meta-heurística, com enfoque na projeção das questões com maior possibilidade de desenvolvimento. Os processos de optimização são um dos campos mais estudados em inteligência artificial, optimização, logística e outras aplicações As principais contribuições deste trabalho foram a identificação das principais questões contidas nos temas de optimização e meta-heurística de processos; uma análise da

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expansão e retração do referido tema; uma compreensão da convergência e divergência; e uma análise das fases de desenvolvimento tal como apresentadas nas lacunas dos cinquenta artigos mais frequentemente mencionados. O principal achado deste trabalho foi analisar o desenvolvimento de tópicos de investigação sobre processos de optimização e meta-heurística, concentrando-se na projeção dos tópicos mais susceptíveis de se desenvolverem.

Palavras-chave: Optimização; Modelação; Algoritmo; Meta-heurística.

1 Introduction

The development of Algorithms started back in the 1960s. The rate at which new Algorithms are introduced has increased steadily. The significant increase in the last decade shows that there is a growing number of researchers who have contributed to the research area (Rajpurohit et al., 2017). Optimization processes is one of the most studied fields in artificial intelligence, optimization, logistics, and other applications. An optimization problem, in mathematics or computer science, is a problem of finding the best solution from all feasible solutions. The optimization problem can be divided into two categories depending on whether the variables are continuous or discrete (Askarzadeh, 2016a; Aydoğdu et al., 2016; Fallah et al., 2018; Osaba et al., 2016). Algorithms that solve optimisation problems consist of finding the best combination among a set of variables to enhance a function, normally known as the objective function or the cost function (Álvarez & Munari, 2016; Dang et al., 2019; Mitić et al., 2015; Mohamed, 2017).

These problems can be divided into three main categories: variables with real values, variables with discrete variables, or variables that mix whole and continuous elements (Gomes et al., 2019; Rafieerad et al., 2017). Problems involving optimisation tend to be problems of maximising or minimising a function of one or more variables within a certain domain; normally, there is also a set of restrictions on the variables (Aydoğdu et al., 2016; Xie et al., 2017). The algorithms that are used for solving an optimisation problem can be essentially deterministic or probabilistic (Andrade et al., 2019; Mohamed et al., 2013; Yu & Li, 2015). Computers are often the only practical approach for handling algorithms. Optimisation algorithms need computer resources and specific systems in order to be handled, for example: physical configurations, cybernetic configurations, and modelled systems (Chen et al., 2006; Rajpurohit et al., 2017).

The systems are interconnected through networks, in order to share resources and information between themselves, through a continuous connection (Ari et al., 2016; Bagheri Tolabi et al., 2015). Programming languages treat the data in a computer using algorithms. An algorithm is a structure showing how a certain problem should be solved (Abd Elaziz et al., 2017). Programming needs the use of special tools and operations within the realm of Mathematical Logic (Rafieerad et al., 2017). An Algorithm is a finite sequence of actions, seeking to find a solution to problems. Algorithms are precise mechanical, efficient and correct procedures, without ambiguity and with finite characteristics (Rajpurohit et al., 2017). An Algorithm also represents a computer program and also the steps needed for carrying out a task. It can be implemented through a computer (Osaba et al., 2016). Different algorithms can carry out the same task using a different set of instructions, in more or less time, and using more or less space or effort than others (Isinkaye et al., 2015; Rajpurohit et al., 2017).

Artificial Intelligence (AI) is the generic name given to the development of programs attempting to construct an artificial form of human intelligence. AIs allow problems to be solved through learning and through inference of information with associative memory and systems based on knowledge (Çaliş & Bulkan, 2015; Companez & Aleti, 2016). The search methods consist of a set of elements, each being identified by a special key. The aim of this search is to find, within this set, the element that corresponds to a specific key. Data structures can be used for conducting searches, making the search process more efficient (Aydoğdu et al., 2016; Santini et al., 2018).

According to research carried out on the Scopus database, there are nine articles that combine bibliometric studies with processes for optimisation of metaheuristics. Despite the nine articles identified in Scopus, these four others were chosen because they are studies that are closer to the main objective of this paper. Neumuth et al. (2012) compared models for progression of surgical interventions, as grounds to back up medical decisions. Cheng et al. (2014) carried out a study analysing PubChen applications in 1,132 articles, seeking pharmacological and genetic development. Romasanta et al. (2018) carried out research about Drugs based on fragments (FBDD), with the application of methods of optimisation. Li et al. (2019) carried out a bibliometric study with the analysis of studies on carbon capture and storage. Even though all these studies have made essential contributions for fields such as medicine, pharmacology, and environmental studies, among others, there was no identification of any study that investigated the processes of optimisation and metaheuristics, without this being linked to a certain field of action.

The main contributions of this work are the identification of the main themes in optimization and meta-heuristic processes and the mapping of research trends in the area of Optimization" and "Metaheuristic Techniques. The motivations for conducting this work is the scarcity of studies that identify what are the most relevant trends in process optimization (Faris et al., 2018; Karagöz & Yıldız, 2017).

Due to the lack of studies observed with regard to this field, in this research study we seek to shed light on the question: what are the most relevant trends on the research themes addressed by optimisation and metaheuristics processes, with a focus on projection of those issues that have the greatest possibility of development. This work is organised in four sections, considering the introduction (the concepts and theoretical foundations related to the theme are presented), the method used in conducting this research study and its stages, the results found, and the discussion of these results and the general conclusions, followed by the references.

2 Literature review

The algorithms aim to solve problems such as the Traveling Salesman Problem and Economic Dispatch. These problems can be solved by algorithms such as: Crow Search Algorithm (CSA) inspired by the nature of crows (Askarzadeh, 2016b), Symbiotic Organism Search (SOS) based on the population as a whole (Abdullahi et al., 2016), Ant Colony Optimization (ACO) which analyzes the behavior of the chewing gears (Bagheri Tolabi et al., 2015; Kalra & Singh, 2015), Genetic Algorithm (GA) inspired by the evolution seen in nature (Kalra & Singh, 2015), Particle Swarm Optimization (PSO) that analyzes the social behavior of particles and is motivated by the social behavior of flocks of birds (Ehsan & Yang, 2018; Kalra & Singh, 2015), League Championship (LC) Algorithm inspired by sports team competitions in a sports association (Kalra & Singh, 2015), Bat Algorithm (BA) which is based on the behavior of bats (Adarsh et al., 2016; Kalra & Singh, 2015; Osaba et al., 2016), among others. Algorithms have been evolving over time, some have a variant that optimizes their performance in a specific situation. One example is the Discrete Symbiotic Organism

Search which is a variation of the Symbiotic Organism Search, this variation was developed to solve problems in the cloud (Abdullahi et al., 2016).

CSA is an optimization algorithm that tries to simulate the intelligent behavior of crows to find the solution of optimization problems, for this it uses two adjustable parameters, they are flight length and awareness probability, this awareness probability parameter is directly used to control the diversity of the algorithm, which makes it attractive for applications in different engineering areas, and its usefulness is evaluated by solving different engineering design problems that have different nature of objective functions, constraints and decision variables (Askarzadeh, 2016b). SOS is population-based to solve numerical optimization problems in a continuous real space. SOS is a repetitive process used to solve optimization problems. The procedure maintains a population of organisms that portray the candidate solutions of the studied problem. Relevant information regarding decision variables and a fitness value are encapsulated in the organism as an indicator of its performance. Essentially, the trajectories of the organisms are modified using the phases of symbiotic association. DSOS is a variant of SOS presented and applied to solve task scheduling problems in a cloud computing environment, with the task scheduling formulated as a discrete optimization problem (Abdullahi et al., 2016).

ACO is a technique based on swarm intelligence used for solving combinatorial problems. The ACO algorithm is originally inspired by the biological behavior of ants and specifically their mode of communication. This inspiration comes from the ability of real ants to find the short paths in their movements to and from their nests when searching for food sources (Bagheri Tolabi et al., 2015; Kalra & Singh, 2015). GA was first introduced by Holland in 1975 and represents a population optimization method based on a metaphor of the evolution process observed in nature. In GA, each chromosome (individual in the population) represents a possible solution to a problem and is composed of a string of genes (Kalra & Singh, 2015).

PSO is an evolutionary computational technique introduced by Kennedy and Eberhart in 1995, inspired by the social behavior of particles and primarily motivated by the social behavior of flocks of birds. Each particle is aliased with position and velocity and moves through a multidimensional search space. In each iteration, each particle adjusts its velocity based on its best position and the position of the best particle in the entire population. PSO combines local search methods with global search methods, trying to balance exploration and exploitation. The popularity of PSO stems from its simplicity and its usefulness in a wide range of applications with low computational cost (Ehsan & Yang, 2018; Kalra & Singh, 2015).

LCA is a metaheuristic algorithm proposed by Kashan for global optimization in 2009. It is inspired by the competitions of sports teams in a sports association. LCA has been used to solve various optimization problems of which some are traveling salesman problems, reactive power dispatch problems, job scheduling and electromagnetic device optimization, cloud job scheduling. LCA works in a way that after each week a league schedule is designed so that teams play in pairs and the outcome is in the form of victory or defeat depending on the playing strength of a team following a meticulous team formation/play technique. Based on the knowledge of the previous week, the team makes changes in the formation for the following week's competition and the league continues until the specified number of seasons (Kalra & Singh, 2015). The Bat algorithm is an algorithm for global optimization, inspired by the echolocation behavior of bats, with varying pulse rates of emission and volume. Bats use echolocation to estimate the distance to their prey. They fly randomly with a speed, position, frequency, noise and emission pulse rate to search for their prey (Adarsh et al., 2016; Kalra & Singh, 2015; Osaba et al., 2016).

3 Scientific method

This section will discuss the method used to develop the research. The research can be classified as applied exploratory and quantitative approach. As method and technical procedures adopted, respectively, by bibliometric research and literature review (Espuny et al., 2021; Kothari & Garg, 2019; Leoni et al., 2017; Reis et al., 2020a). Figure 1 shows Methodological flow of the research.

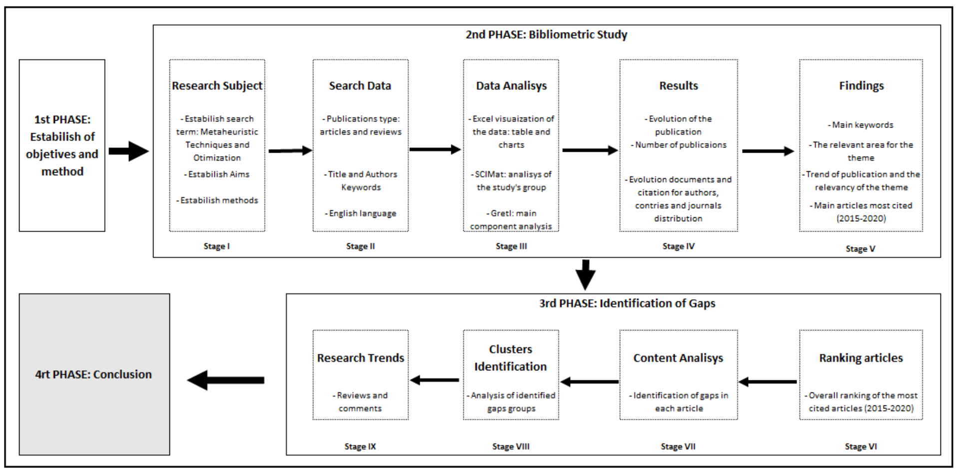

Figura 1. Research method.

This research study was carried out in four phases namely: (1) establishment of theme, goals, and methods; (2) Carrying out bibliometric studies; (3) identification of gaps, analysis of evolution and convergence between the issues, and (4) conclusion.

In the First Phase, there was establishment of the theme, the goal, and the method of research. The Second Phase includes five separate stages: (I) subject of the research, (II) research data, (III) analysis of data, (IV) results, and (V) findings:

- In Stage I, the Scopus database was established and the descriptors used "Optimization" and "Metaheuristic Techniques" used in the research and the methods and research Bibliometric Analysis and Content Analysis;
- In Stage II, the most cited articles were defined and only those published in English were considered, as it is the most commonly used language in science (Reis et al., 2021). Articles from the period between 2012 and 2020 were considered, resulting in 1,513 articles. Data were collected in the month of May 2020;
- In Stage III, the data was organised in table and graph form. The programs used to allow illustrations of data processing were software packages such as Microsoft Excel, SCIMat and Gretl;
- In Stage IV, the development of publications between 2012 and 2020 was mapped, with regard to publications on Metaheuristics in Process Optimisation; and
- In Stage V (Findings), we identified the main key words related to publications on Metaheuristics in Process Optimisation, and this information was also subjected to

a percentage point analysis and an analysis of the main components, to analyse the themes present in this field of knowledge that have a potential to increase or decrease.

Phase 3 includes four stages, namely: (VI) Classification of Articles; (VII) Analysis of Content; (VIII) Identification of Clusters, and (IX) Group Analysis:

- In Stage VI, the 50 most cited articles (Appendix A) between 2015 and 2019 were selected, as the most recent articles reflect the current scenario of the topic (Alvarenga et al., 2021; Reis et al., 2020b);
- In Stage VII, we identified gaps in the research for each article. To identify these gaps, we sought to highlight suggestions for future studies through the publications as analyzed (explicit gaps) and through suggestions of studies that could use the same models as proposed by the authors in other contexts (implicit gaps) in cases where these do not exist;
- In Stage VIII (Identification of Clusters) all the gaps as identified were placed in categories; and
- An analysis of each of the trends as identified is made in Stage IX (Group Analysis).

Phase 4 was affected by a pair of previous phases, thereby allowing the understanding of the start of the art to trace the most promising paths for Metaheuristics in Process Optimisation in the following years.

4 Results

According to Price's Law, the academic production of a certain field of knowledge tends to grow exponentially, and shall then split into four different phases, as shown in Figure 2 (Cristino et al., 2018).

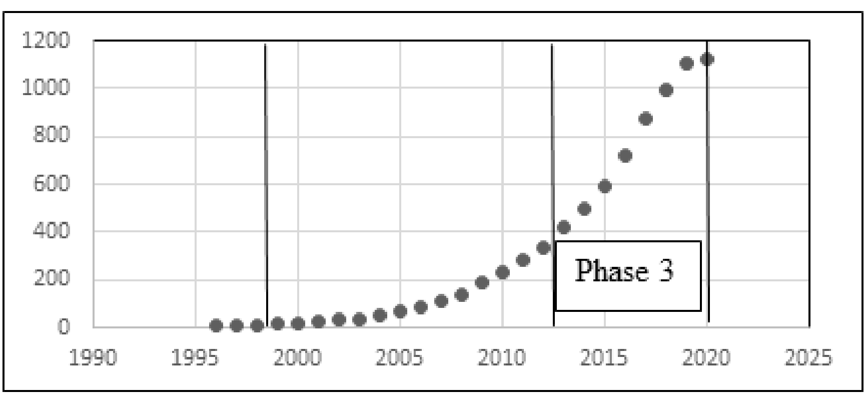

Figura 2. Phases in Growth of Publications.

The main hypothesis of Price's Law is that scientific development takes place through exponential growth, and that the domain of human knowledge passes through four phases (Dabi et al., 2016). In Figure 2, we can see Phase 1 (forerunner, from 1996 to 1998); Phase 2 of exponential growth, which presented some 29% of the publications of all periods as analysed (1999-2012); Phase 3, of linear growth, which presented more than 70% of the period (2013-2019), and the hypothetical Phase 4, which is not yet clear, from the maturity domain (after 2019), which may have been reached this year, as it appears to be a turning point.

In Table 1, we have sought to bring together all the key words that make up a certain area of knowledge, based on the key principle that the groupings with a common nature allow grounds for analysis of theme blocks as contained in this same field (Cobo et al., 2012; Phillips et al., 2015). Each period analysed corresponds to a period of two years, involving the period of linear growth, except for the last year of the exponential period as present in the field.

Table 1. Development of research themes.

	PERIOD CLUSTER	1	2012 and 2013	2	2014 and 2015	3	2016 and 2017	4	2018 and 2019	(2-1)	(3-2)	(4-3)	(4-2)
1	ALGORITHM VARIATIONS	87	64.44%	132	75.00%	215	76.51%	159	68.53%	10.56%	1.51%	-7.98%	-6.47%
2	ARTIFICIAL INTELLIGENCE	18	13.33%	30	17.05%	53	18.86%	35	15.09%	3.71%	1.82%	-3.78%	-1.96%
3	COMPUTER RESOURCES	31	22.96%	40	22.73%	73	25.98%	73	31.47%	-0.24%	3.25%	5.49%	8.74%
4	CONTROL METHODS	10	7.41%	14	7.95%	26	9.25%	25	10.78%	0.55%	1.30%	1.52%	2.82%
5	METAHEURISTIC TECHNIQUES	79	58.52%	88	50.00%	139	49.47%	108	46.55%	-8.52%	-0.53%	-2.91%	-3.45%
6	NETWORKS	9	6.67%	12	6.82%	42	14.95%	32	13.79%	0.15%	8.13%	-1.15%	6.97%
7	PROCESS OPTIMISATION	85	62.96%	128	72.73%	225	80.07%	192	82.76%	9.76%	7.34%	2.69%	10.03%
8	SCHEDULING	16	11.85%	31	17.61%	41	14.59%	45	19.40%	5.76%	-3.02%	4.81%	1.78%
9	SEARCH METHODS	30	22.22%	32	18.18%	46	16.37%	45	19.40%	-4.04%	-1.81%	3.03%	1.21%
10	SYSTEM TYPES	14	10.37%	34	19.32%	75	26.69%	69	29.74%	8.95%	7.37%	3.05%	10.42%
11	MISCELLANEOUS PROBLEMS	25	18.52%	32	18.18%	58	20.64%	45	19.40%	-0.34%	2.46%	-1.24%	1.21%
	TOTAL DOCUMENTS		**135**		**176**		**281**		**232**				

After the grouping, we checked the variation in terms of percentage points for each field, so that we may include the themes with potential for increase or decrease, for each research theme. We considered the main parameter to be the difference between the fourth and second period (the last column of this table), due to the fact that the 4th period includes the most recent information and the fact that the 2nd period has a higher level of maturity, compared to the 1st. The fields with greatest percentage variations were ‘System Types’ (10.42%), “Process Optimisation” (10.03%) and ‘Computer Resources’ (8.74%). This appears to suggest that these themes could be more promising than the others present in this field of knowledge. Algorithms and Metaheuristics follow a significant downward trend, as according to the preparation of these studies.

In Figure 3, it becomes clear that in the major theme ‘Types of Systems’, there was no decline in the use of the terms that comprise it, even though there are signs of possible deceleration between periods 3 and 4. The themes of ‘Variations of Algorithms’, ‘Artificial Intelligence’ and ‘Miscellaneous Problems show the most significant declines between the last two periods analysed.

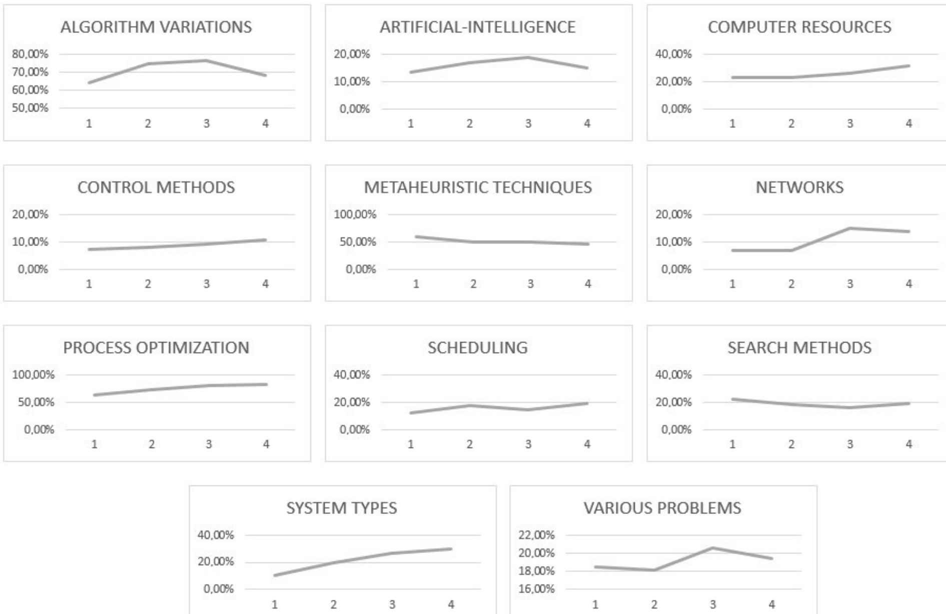

Figura 3. Development Trends of the research themes.

Regarding the other themes within this field, there is a state of stability. Figure 4 shows the Principal Components Analysis. The analysis stated was carried out, to see which groups of themes show greatest convergence. The data used for processing the calculations was the same as used in Figure 4, when we calculated the number of mentions for each research theme, based on key words, based on the total number of documents as published in the two-year periods between 2012 and 2019.

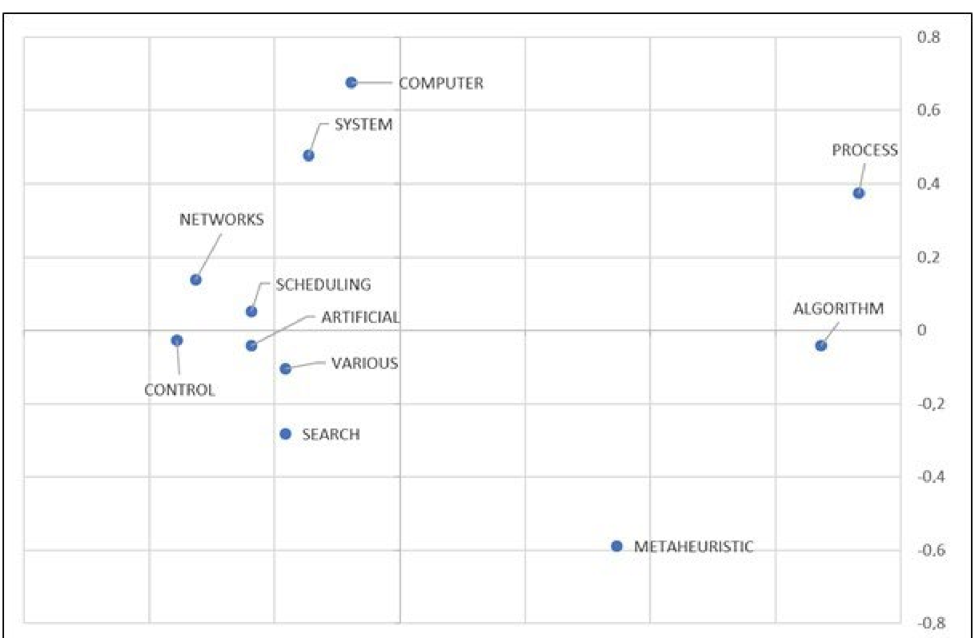

Figura 4. Analysis of Main Components.

With the application of the Gretl software, it was discovered, based on the data supplied, that the first two eigenvectors provided an accumulation of 0.9950; thereby allowing the graphical description with a high rate of reliability. The Principal Components Analysis was performed as of the correlation matrix of the data, based on Equation 1 (Varella, 2008).

$$\frac{Var\left(Y_1\right)+\ldots Var\left(Y_k\right)}{\sum_{i=1}^{k} Var\left(Y_i\right)}.100 \geq 70\% \, where \, k < p \tag{1}$$

Process Optimisation shows itself to be somewhat more distant, as also Metaheuristics and Algorithms were well distant from the others. As a possible hypothesis, we can consider the fact that these three fields present average results of 50% in the periods considered here (2012-2019), because they concentrate the most elementary terms of the knowledge field. ‘Artificial Intelligence’ and ‘Miscellaneous Problems’ were close to the graph for analysis of main components, as shown in Figure 4. The main hypothesis is the fact that the software can have the support of IA for problem solving. There was some approximation between ‘Network’ and ‘Scheduling’, also because Scheduling, in close alliance with the Network, is essential for the optimisation of processes.

The next step of the research was carrying out content analysis, which is a widely used qualitative technique, seeking to provide greater reliability of information obtained (Hsieh & Shannon, 2005).

It was also observed that, after the analysis of the content of the articles, to group the information and carry out syntheses that could contribute to the scientific progress of this field, we observed that the 50 documents (most cited) as analyzed could be distributed among phases of complete development of a given System. To establish the stages it was used the adaptation of the “PLAN-DO-CHECK-ADJUST” concept, establishing the stages “Projects”, “Test”, “Implementation” and “Assessment” (Garza-Reyes et al., 2018; Prashar, 2017; Silva et al., 2017), as shown in Table 2 and Figure 5.

Table 2. Research Trends.

Project	(Abd Elaziz et al., 2017; Adarsh et al., 2016; Askarzadeh, 2016b; Aydoğdu et al., 2016; Çaliş & Bulkan, 2015; Chen et al., 2016; Chou & Pham, 2015; Ehsan & Yang, 2018; Fallah et al., 2018; García-Torres et al., 2016; Heidari et al., 2019; Karagöz & Yıldız, 2017; Labbi et al., 2016; Maleki et al., 2016; Mukhopadhyay et al., 2015; Nabil, 2016; Osaba et al., 2016; Rajpurohit et al., 2017; Ramadan et al., 2017; Sadollah et al., 2015; Salido et al., 2016)
Test	(Dell'Amico et al., 2016; Faris et al., 2018; Kalra & Singh, 2015; Mafarja et al., 2019; Medani et al., 2018; Mellal & Williams, 2015; Rafieerad et al., 2017; Senthilnath et al., 2016; Yu & Li, 2015)
Implementation	(Ahmad et al., 2016; Bandyopadhyay & Mukherjee, 2015; Dhiman & Kumar, 2017; Mitić et al., 2015)
Evaluation	(Abdullahi et al., 2016; Abualigah et al., 2018; Al-Dabbagh et al., 2018; Ari et al., 2016; Askarzadeh, 2016a; Bagheri Tolabi et al., 2015; Caraveo et al., 2016; Chau, 2017; Dhiman & Kumar, 2018; Hasançebi & Azad, 2015; Heidari et al., 2017; Saka et al., 2016; Saxena & Kothari, 2016; Secui, 2016; Silva et al., 2015; Tien Bui et al., 2016)

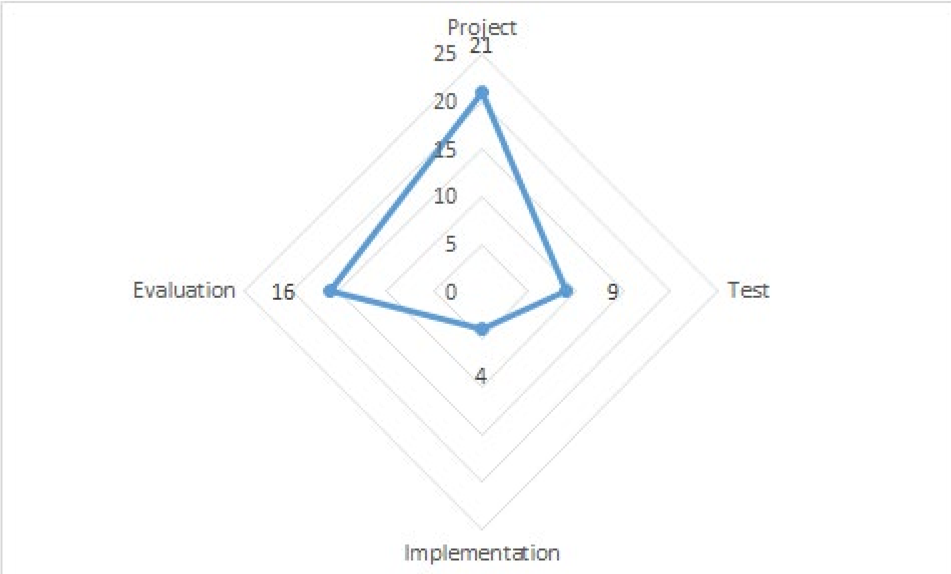

Figura 5. Groups of Research Gaps.

Due to the moment of initial growth, where many propositions (Projects) are identified that need to be tried out in practice (tests) (Appendix A). So it is ide that the main indications of studies foreseen in the publications suggest the realization of 'Projects' and then 'evaluation'. The proposal of 'Testing' and 'implementation' were not relevant, suggesting that at that moment, according to the most commonly cited articles, there is a less significant degree of academic interest focused on these development phases.

5 Conclusion

The purpose of this article, that of showing the development of research issues on processes of optimisation and metaheuristics, with a focus on the projection of the themes with greatest likelihood of development, has indeed been duly attained. It was observed that the knowledge area is at an inflection point, so it will only be possible to observe if there will be stagnation of publications after the end of the analyzed period, that is, at the end of this year (2021).

The main academic contributions of this work were the identification of the main themes contained in optimization processes and metaheuristics; the analysis of expanding themes and those that are contracting; the understanding of the convergence and distancing between themes; and the analysis of the development phases presented in the gaps of the fifty most referenced articles. The main practical contributions are the mapping to be able to direct future research in the area of “Optimization” and “Metaheuristic Techniques”.

We see that publications are most focused on 'Types of Systems', 'Process Optimization' and 'Computing Resources'; those that are most significant within the development of 'Design'. One possibility that 'Design' has been more prominent than other phases of development is that the number of ideas is growing, or perhaps it has not been possible to transfer them to other scientists to pursue, or possibly they have not yet been made available to the market. As a proposition for future studies are research that delves into the advantages and disadvantages of metaeuristic methods and algorithms.

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Appendix A. Scientific Gaps in The Topic Of Optimization Variables.

#	Title	Authors (year)	Scientific Gap
1	A novel metaheuristic method for solving constrained engineering optimization problems: crow search algorithm	Askarzadeh (2016a)	Analyze the advantages that the meta-heuristic optimizer raven search algorithm provides
2	Symbiotic organism search optimization based task scheduling in cloud computing environment	Abdullahi et al. (2016)	Analyze the advantages of the search algorithm symbiotic organism scheduling
3	A review of metaheuristic scheduling techniques in cloud computing	Kalra & Singh (2015)	Identify the applicability of meta-heuristic scheduling algorithm for cloud environments
4	An improved discrete bat algorithm for symmetric and asymmetric traveling salesman problems	Osaba et. Al (2016)	Propose a descriptive reversal of the improved discrete bat algorithm for process optimization
5	A social spider algorithm for global optimization	Yu & Li (2015)	Identify the feasibility of the swarm intelligence algorithm inspired by the social nature of spiders in optimization processes
6	Economic dispatch using chaotic bat algorithm	Adarsh et al. (2016)	Propose a comparison of chaotic sequences for optimization problems
7	Harris hawks optimization: algorithm and applications	Heidari et al. (2017)	Propose the use of the harris hawks optimizer method for problem solving
8	Simultaneous reconfiguration, optimal placement of dstatcom, and photovoltaic array in a distribution system based on fuzzy-aco approach	Bagheri Tolabi et al. (2015)	Evaluate the feasibility of combining a multi-objective fuzzy effect with ant colony optimization
9	A modified flower pollination algorithm for global optimization	Nabil (2016)	Propose an improved variant of the flower pollination algorithm in solving optimization problems
10	Hybrid artificial intelligence approach based on neural fuzzy inference model and metaheuristic optimization for flood susceptibilitgy modeling in a high-frequency tropical cyclone area using gis	Tien Bui et al. (2016)	Identify the advantages of artificial intelligence based on fuzzy neural inference system in process optimization
11	Optimal integration and planning of renewable distributed generation in the power distribution networks: a review of analytical techniques	Ehsan & Yang (2018)	Propose the use of artificial intelligence to optimize the planning and distribution of renewable energy
12	Hybrid methods for fuzzy clustering based on fuzzy c-means and improved particle swarm optimization	Silva et al. (2015)	Evaluate the feasibility of hybrid methods in the optimization of processes with multiple output variables
13	A new feature selection method to improve the document clustering using particle swarm optimization algorithm	Abualigah et al. (2018)	Evaluate the benefits of bayesian calibration to build energy simulation
14	Chaotic fruit fly optimization algorithm	Mitić et al. (2015)	Implement new fruit fly algorithm and optimization method in practical studies
15	Spotted hyena optimizer: a novel bio-inspired based metaheuristic technique for engineering applications	Dhiman & Kumar (2017)	Systematize the new metaheuristic algorithm called spotted hyena optimizer and identify new applications
16	Emperor penguin optimizer: a bio-inspired algorithm for engineering problems	Dhiman & Kumar (2018)	Identify the difficulties when implementing the emperor penguin optimizer optimization algorithm in engineering problems
17	Computational intelligence techniques for hvac systems: a review	Ahmad et al. (2016)	Systematize the benefits of using computational intelligence in the optimization of problems in heating, ventilation and air-conditioning systems
18	An algorithm for many-objective optimization with reduced objective computations: a study in differential evolution	Bandyopadhyay & Mukherjee (2015)	Implement the algorithm for many-objective optimization in practical studies
19	A survey of multiobjective evolutionary clustering	Mukhopadhyay et al. (2015)	Describe evolutionary clustering techniques in the optimization of processes with multiple output variables

Appendix A. Continued...

20	An improved opposition-based sine cosine algorithm for global optimization	Abd Elaziz et al. (2017)	Identify the possibilities of applicability of the cosine sine opposition-based algorithm
21	An efficient chaotic water cycle algorithm for optimization tasks	Heidari et al. (2017)	Identify the benefits in optimizing processes with multiple output variables by implementing the water cycle algorithm
22	Metaheuristics in structural optimization and discussions on harmony search algorithm	Saka et al. (2016)	Describe the benefits of applying meta-heuristic algorithms to the optimization of everyday problems
23	Optimization of fuzzy controller design using a new bee colony algorithm with fuzzy dynamic parameter adaptation	Caraveo et al. (2016)	Analyze and describe the multi-agent systems techniques for optimizing climate control systems
24	Water cycle, mine blast and improved mine blast algorithms for discrete sizing optimization of truss structures	Sadollah et al. (2015)	Propose the implementation of the fuzzy bco method
25	Parameters identification of photovoltaic models using hybrid adaptive nelder-mead simplex algorithm based on eagle strategy	Chen et al. (2016)	Propose the operation of an adaptive nelder-mead simplex enhanced with the artificial bee colony metaheuristic on different types of systems
26	Use of meta-heuristic techniques in rainfall-runoffmodelling	Chau (2017)	Analyze and describe the benefits of using rainfall runoff modeling metaheuristic techniques in process optimization
27	A power efficient cluster-based routing algorithm for wireless sensor networks: honeybees swarm intelligence based approach	Ari et al. (2016)	Identify the benefits of the cluster-based routing protocol called abc-sd
28	Smart artificial firefly colony algorithm-based support vector regression for enhanced forecasting in civil engineering	Chou & Pham (2015)	Propose a new support vector regression based on the firefly algorithm in process optimization
29	A comparison of recent metaheuristic algorithms for crashworthiness optimisation of vehicle thin-walled tubes considering sheet metal forming effects	Karagöz & Yıldız (2017)	Map the search fields of process optimization algorithms
30	A genetic algorithm for energy-efficiency in job-shop scheduling	Salido et al. (2016)	The application refers exclusively to the use of clusters for specific application in energy consumption in sensors
31	Algorithmic design issues in adaptive differential evolution schemes: review and taxonomy	Al-Dabbagh et al. (2018)	Identify the benefits of algorithmic design schemes that have been used in variants of differential evolution
32	Capacitor placement in distribution systems for power loss reduction and voltage improvement: a new methodology	Askarzadeh (2016b)	Identify applications for the newly developed metaheuristic, raven search algorithm
33	High-dimensional feature selection via feature grouping: a variable neighborhood search approach	García-Torres et al. (2016)	Identify the applicability of the neighborhood variable search algorithm in multiple output variable processes
34	Particle swarm optimization algorithm for capacitor allocation problem in distribution systems with wind turbine generators	Ramadan et al. (2017)	Map the new applications for the particle swarm optimization method
35	Design of a cost-effective wind/photovoltaic/hydrogen energy system for supplying a desalination unit by a heuristic approach	Maleki et al. (2016)	Implement a model of a hybrid photovoltaic, wind and hydrogen desalination system to increase the availability of fresh water
36	A modified symbiotic organisms search algorithm for large scale economic dispatch problem with valve-point effects	Secui (2016)	Identify the weaknesses of modified symbiotic organisms search algorithm
37	Adaptive dimensional search: a new metaheuristic algorithm for discrete truss sizing optimization	Hasançebi & Azad (2015)	Identify the weaknesses of the adaptive dimensional search algorithm
38	Toward improved mechanical, tribological, corrosion and in-vitro bioactivity properties of mixed oxide nanotubes on ti–6al–7nb implant using multi-objective pso	Rafieerad et al. (2017)	Identify the applicability of the particle swarm optimization algorithm in processes with multiple output variables
39	Glossary of metaheuristic algorithms	Rajpurohit et al. (2017)	Systematize the algorithms that can be applied to processes with multiple output variables

Appendix A. Continued...

40	A destroy and repair algorithm for the bike sharing rebalancing problem	Dell′Amico et al. (2016)	Identify the applicability of the destroy and repair algorithm in process optimization
41	Computational intelligence approaches for energy load forecasting in smart energy management grids: state of the art, future challenges, and research directions	Fallah et al. (2018)	Systematize main intelligent computational methods in power load forecasting in smart grids
42	Ant lion optimization algorithm to control side lobe level and null depths in linear antenna arrays	Saxena & Kothari (2016)	Identify the benefits of the ant lion optimization algorithm in electromagnetics
43	A new rooted tree optimization algorithm for economic dispatch with valve-point effect	Labbi et al. (2016)	Identify the applicability of the root tree optimization algorithm in process optimization
44	Design optimization of real world steel space frames using artificial bee colony algorithm with levy flight distribution	Aydoğdu et al. (2016)	Identify the applicability of the artificial bee colony algorithm in multiple output variable processes
45	A research survey: review of ai solution strategies of job shop scheduling problem	Çaliş & Bulkan (2015)	Map the main causes of job shop scheduling problems
46	A novel approach for multispectral satellite image classification based on the bat algorithm	Senthilnath et al. (2016)	Identify the applicability of the bat algorithm in processes with multiple output variables
47	Cuckoo optimization algorithm with penalty function for combined heat and power economic dispatch problem	Mellal & Williams (2015)	Identify the applicability of the cuckoo optimization algorithm in processes with multiple output variables
48	Binary grasshopper optimisation algorithm approaches for feature selection problems	Mafarja et al. (2019)	Identify the applicability of the grasshopper optimization algorithm in processes with multiple output variables
49	Whale optimization algorithm based optimal reactive power dispatch: a case study of the algerian power system	Medani et al. (2018)	Identify the applicability of the whale optimization algorithm in processes with multiple output variables
50	A multi-verse optimizer approach for feature selection and optimizing svm parameters based on a robust system architecture	Faris et al. (2018)	Identify which are the most relevant trends in process optimization