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HOW COMPLEX IS IT TO UNDERSTAND COMPLEXITY? A systematic study of complexity and decision making

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1 INTRODUCTION

Complexity is deeply ingrained in life. Humans face complexity in the most routine decisions, such as choosing the toppings of a pizza or find a friend in the middle of a crowded train station during rush hour. And of course, complexity is present also in important decisions in life as choosing the courses offered at graduate school, career decisions, love life and which retirement or health plan to pay. Other animals also must make complex decisions, as exemplifies Michalski et al. (2020), if a rabbit is running away from a fox, it must consider a variety of escape routes that may reveal themselves as the chase unfolds. In the field of artificial intelligence (AI) machines – created by humans – face complex problems too.

Even though there is a consensus in literature that complexity is an important fact that influences and predicts behavior, it is also known that the definition of complexity is far from clear (Liu & Li, 2012; Campbell, 1988). Rescher (1998, p. 8) perfectly describe it when stating "complexity itself is a markedly complex idea". This stems from the diversity of research fields that are dedicated to the study of complexity, from astrophysics to social sciences (Rescher, 1998).

Understand the effect of complexity in human performance and behavior is imperative for the field of decision-making, whereas is assumed that human computational resources are limited (Simon, 1955). The capacity to make a decision and the human performance depends on the decision-maker limited resources and also depends on the resources required for the situation. The purpose of this paper is to understand how the complexity and decision-making are interconnected as scientific knowledge. To achieve this objective was used the technique of bibliometrics for scientific mapping. Following the proposal of Aria and Cuccurullo (2017) we aim to: *i)* examine the conceptual structure of studies that investigate complexity and decision-making; *ii)* identify the knowledge base regarding these topics and its intellectual structure; and *iii)* present a social network structure of these scientific community.

This research advances in the theoretical field of decision-making because even though complexity has already been proven to affect human decision-making, many of today's decision-making models ignore or address the complexity of choice only informally (Franco et al., 2020). It also helps to clarify the complexity construct and its use in research. Many studies have been proposed with the aim of clarifying concepts of complexity in different areas (see Liu & Li, 2012), but we have not found a study with the same objective as this one.

This article is structured as follows: a brief theoretical background is presented covering a general definition of complexity and the complexity in decision-making. Then the methodology is exposed, where is detailed the entire conduct of the study. Subsequently, each research objectives are addressed in the results discussion sessions. Finally, the main conclusions and limitations of the study are presented.

2 THEORETICAL BACKGROUND

2.1 Complexity: a general definition

Based on the assumption that complexity alone is a complex concept first we will define it. Research on complexity is present in different fields and perhaps that is why it has different conceptions according to the paradigms of the field. From philosophy to chemistry, from pedagogy to computer science, several authors have tried to answer, "What is complexity?".

From an evolutionary view, complexity can be measure as the amount of information that a biological organism stores about the environment in which it evolves. On the other hand, complexity is related to structure in the study of dynamic systems in the field of physics. As all processes can be materialized as computations, complexity is usually measured in terms of time (i.e., the number of operations required), and in terms of space (i.e. the amount of memory required) to found a solution for a problem (Bossaerts & Murawski, 2017) in dynamic systems theory. In the mathematical field the definition of complexity is concerned with the intrinsic regularities of a sequence (Adami, 2002). Most of these definitions come from the study of complex systems and the interactions between different parts or sub-system, emphasizing the structure or behavior of the system.

Rescher (1998) addresses these numerous concepts and applications of complexity in different fields. Table 1 presents the modes of complexity from Rescher (1998). This model synthesizes the main characteristics of complexity and acknowledges both subjective and objective nature of complexity.

Table 1
Modes of Complexity

	Epistemic Modes	
Formulaic Complexity	Descriptive Complexity	Length of the account that must be given to provide an adequate description of the system at issue.
	Generative Complexity	Length of a set of instructions that must be given to provide a recipe for producing the system at issue.
	Computational Complexity	Amount of time and effort involved in resolving a problem
	Ontological Modes	
Compositional Complexity	Constitutional Complexity	Number of constituent elements or components (compare, for example, tricycles, automobiles, and jet aircraft).
	Taxonomical Complexity (Heterogeneity)	Variety of constituent elements: number of different kinds of components in their physical configurations (consider again of the preceding example or compare the domain of physical elements which come in some 100-plus types with that of insects of which there are many thousands of species).
Structural Complexity	Organizational Complexity	Variety of different possible ways of arranging components in different modes of interrelationship (compare jigsaw puzzles with their two-dimensional arrangements with LEGO blocks with their three-dimensional modes of assembly).
	Hierarchical complexity	Elaborateness of subordination relationships in the modes of inclusion and subsumption. Organization disaggregation into sub-systems (For example: particles, atoms, molecules, macrolevel physical objects, stars and planets, galaxies, galactic clusters, etc.; or again: molecules, cells organs, organisms, colonies). Here the higher-order unit are, for this very reason, always more complex than the lower-order ones.
	Functional Modes	
Functional Complexity	Operational Complexity	Variety of modes of operation or types of functioning (Primates have a more complex lifestyle than mollusks. The processual structure of chess is vastly more elaborate than that of checkers).
	Nomic Complexity	Elaborateness and intricacy of the laws governing the phenomena at issue (steam engines are more complex in this manner than pulleys).

Note: From Rescher, N. (1998). *Complexity: A philosophical overview*. Transaction Publishers.

The next section discusses the complexity in decision-making, summarizing the definitions of complexity for this field of study, its application and measurement in research.

2.1 Complexity in Decision-Making

Undeniably, Herbert Simon is one of the most influential researchers in the field of decision-making. In a paper dealing with complexity in problem solving named "The architecture of complexity", he proposed that the complexity of a system can be characterized in terms of levels of hierarchy. In Simon's words "the complex system being composed of subsystems that, in turn, have their own subsystems, and so on" (1962, p. 468). In this view the complexity of a system can be characterized in terms of levels of hierarchy. It derives from the large number of patterns and their multiple interactions.

An in-depth understanding of the complexity has been a topic of discussion among the main authors in the field of decision-making for many years. Campbell (1988) – in the most cited article involving this theme – proposed a review and analysis about the complexity. Complexity is defined based on structure, that is, a given system or task will be complex considering its multiple paths, multiple outcomes, interdependence between paths, conflict and uncertainty. Campbell's (1988) drew an integrative structure with different concepts of complexity considering as: *i)* a psychological experience; *ii)* a task-person interaction; and *iii)* a function of objective characteristics. The objective complexity is a characteristic of a task and independent of the individual. The subjective complexity is a psychological experience or perception of the one who solves the problem.

Wood’s (1986) vision separates the actor and the behavior by expressing complexity as a linear combination of three factors: *i)* component complexity is related to the number of distinct acts required to complete a task; *ii)* coordinative complexity is the relation among the required actions/inputs and products/outputs; *iii)* dynamic complexity is the rate of change in the actions or information.

In a more recent framework Liu and Li (2012) classify Campbell’s (1988) and Wood’s (1986) approach as a structuralist viewpoint. In addition to this category, the authors also discuss the definitions of complexity in more two ways. The resource requirement viewpoint is related to human information processing. The interaction viewpoint of complexity is concern with the subjective complexity imposed on task performers.

Hærem et al. (2015) resume the work of Wood (1986) and Campbell (1988) as the ‘Old Assumption’ and proposes how the theory should deal with complexity nowadays as ‘New Assumption’ (see Table 2). For the authors the dimensions treated in the literature of complexity so far are not often operationalized in empirical research and therefore proposes this new conceptualization of complexity in decision-making tasks.

Observing the evolution from the old to the new assumption we can see individual's behavior towards the task must gain importance in research, while the spectrum of factors affecting complexity must be expanded. The importance of the task performer (or decision-maker) is perfectly summarized by Polanyi (1962), who states that there is no task if there is no one who is doing it (Hærem et al., 2015).

Table 2

Task Complexity Assumptions

Dimensions	Old Assumption	New Assumption
Separability of task from behavior and context	Tasks should be separated from behavior	Tasks are inseparable from behavior
	Tasks are separate from their material context	Tasks are inseparable from material context
	Complexity is a property of an idealized task description	Complexity is indexed by observable behavior
	Complexity is observer independent	Complexity is observer dependent
Level of analysis	Task complexity is an individual level construct	Task complexity applies for any number of actors at any level of analysis
Types of complexity	There are a few predetermined “types” of complexity (component, coordinative, etc.)	There are many mechanisms that can contribute to task complexity
Functional form	Complexity is a linear function of task components	Complexity is an exponential function of task components

Note: From Hærem, T., Pentland, B. T., & Miller, K. D. (2015). Task complexity: Extending a core concept. *Academy of management review*, *40*(3), 446-460.

One last point we add is the relationships and distinctions between complexity and difficulty. These are concepts that are neither independent nor equivalent (Liu & Li, 2012), which creates confusion in their use and in the definition of a decision or task as complex / difficult. Campbell (1988) has already brought up this discussion, stating that the source of the confusion is that complex tasks are difficult by their nature. Difficult tasks require a lot of effort, but they will not always be complex. And a complex task can be difficult for one individual but not for another one (Campbell, 1988). From Liu and Li (2012) the complexity of the task must be treated in terms of its objective characteristics while the difficulty involves the interaction between the task and the task-maker.

We briefly elucidated this discussion to justify our choice of defining the terms of the bibliographic search. As complexity lacks a more precise definition and, in the literature, there seems to be confusion between complexity and difficulty or even the use of terms as synonyms, we chose to use both terms in the field labels in the databases (see methodology).

3 METHODOLOGY

Research with objectives such as our should be carried out using a methodology that allows identifying and examining the publications involved on the topics of interest. Bibliometric analysis is an essential strategy for statistically analyzing a large volume of data and mapping the structure and patterns of scientific development in a field or research topic (Zupic & Čater, 2015). Bibliometric research is characterized as literature review, however, using a systematic, transparent, and reproducible process (Pritchard, 1969).

Systematic review and bibliometric analysis are often used to reveal research patterns and have important applications in research. In this article it is proposed to gather and summarize information from a recent framework – involving two research topics together: complexity and decision-making. We follow the standard workflow proposed by Zupic and Čater (2015) which consists of five stages: 1: Study design; 2: Data collection; 3: Data analysis; 4: Data visualization; 5: Interpretation. These systematic and replicable methods aim to reduce the bias in the accumulation of knowledge and collection of evidence, presenting statistical results of objective and reliable measurement of scientific activity (Pritchard, 1969). Figure 1 summarizes the first and second steps of the workflow. Steps 3, 4 and 5 are explained later.

The first step starts with the definition of the goal and timespan (Zupic & Čater, 2015). Our goal was defined as to understand the development of knowledge about complexity and decision making. We opted for the period between 2000 and 2020 to get a more recent framework. We chose to perform the search with the terms ("complex*" OR "difficult*") AND ("decision making" OR "decision-making" OR "choice"). Boolean operator AND restrict the results that contain all the search terms, and OR connects similar concepts, expanding the search for results that contain any of the search terms. Truncation with the "*" symbol expands the search to several endings and spellings of the same word root. We use the title field label. The results were filtered for the defined timespan and the document type was also filtered for articles only.

In the second step, the database must be defined. Web of Science and Scopus were chosen because they are recognized as the main scientific databases. Both have a large number of high-quality peer-reviewed journals in the areas of administration, management and business when compared to others such as Google Scholar and EBSCO (Ferreira et al., 2016). The search and download in the databases were carried out on April 2, 2021.

Using RStudio software we merge the results of the two databases and exclude the duplicate articles creating a single document with 1,366 publications. The WoS database provides articles with early access. This was a problem for us because the algorithm used by WoS is not able to filter those articles that are linked to the year in which they were made available in the database, but with an early access identification for the following year. We found in our search 14 publications that referred to the year 2021 and returned as early access in the year 2020. These articles were removed in the bibliometrix package in order not to bias the search. Our final sample consists of 1,352 publications. All data retrieved from the database, the script used for merging the files and the final sample are available on OSF anonymous link (https://osf.io/zv9ad/?view_only=0eedee14c03345e18f2e565e02d45f4f).

The tool for data analysis was chosen in the third phase. We opted for bibliometrix software (http://www.bibliometrix.org) which is an R package of tools for quantitative research in bibliometrics developed by Aria and Cuccurullo (2017). Bibliometrix supports the second to fourth stages of the Zupic and Čater (2015) science mapping workflow. The first and fifth stages must be carried out by the researchers. Fourth stage refers to the definition of which analyzes will be used. We performed all the analyzes that the software allowed and selected the most interesting ones for the following discussion which constitutes the fifth stage.

Figure 1
Analytical Framework of the Study

Note: Figure prepared by authors.

In sum, with this research we expected to form a general framework about the literature about decision making and complexity, allowing us to understand paths of previous research as well as to direct future efforts. In the next section, the results are presented and discussed.

4 RESULTS AND DISCUSSION

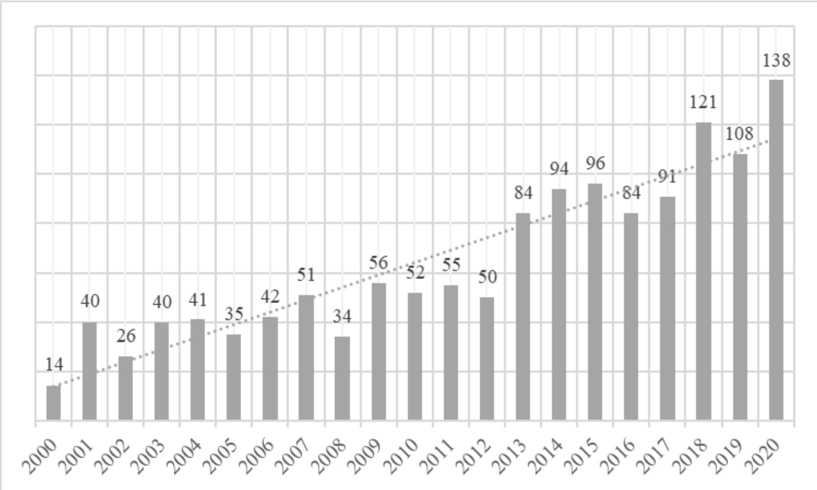
This session presents the results of the scientific mapping previously explained. It is divided into 4 parts: section 4.1 presents a general descriptive analysis of the bibliographic data; section 4.2 examines the conceptual structure of the data set; section 4.3 identifies the knowledge base and its intellectual structure; and in section 4.4 is presented the social network structure.

4.1 Descriptive analysis

This section begins the discussion by presenting a descriptive analysis of the bibliographic data frame. The graph in Figure 2 presents the number of publications per year. The annual growth rate is 12.12%. Since 2013 there has been a considerable increase in the number of articles published compared to previous years. This growth in recent years corroborates with recent authors discussed above (e.g.: Liu & Li, 2012; Hærem et al., 2015) that continue to claim that complexity still needs to be clarified.

Figure 2

Annual Production



Note: Figure prepared by authors with information recovered from Bibiliometrix software analysis.

Table 3 presents 10 most frequent sources ranked by the number of publications. Total number citations for each journal indicates the sum of citations in our dataset and initial year identifies first year that the journal appeared in timespan. The most productive source is the Journal of Career Assessment. It is focused on assessment, career development and vocational psychology, seeking advances in understanding career decision-making. The themes discussed by the source are prominent in this research, appearing in the following analyzes.

PLOS ONE has publications in many areas of knowledge. This source has its first contribution to the framework analyzed in 2012 – less than half of our timespan – and yet it appears as second most frequent sources with 16 publications. The Proceedings of the Royal Society B: Biological Sciences was the periodical with the highest number of citations (839) among the most relevant. This shows the quality of the articles published in this source and its recognition by peers.

Table 3

Most Frequent Sources

Source	Number of publications	Times Citation	Initial Year
JOURNAL OF CAREER ASSESSMENT	22	663	2001
PLOS ONE	16	157	2012
IEEE ACCESS	11	71	2017
BEHAVIORAL ECOLOGY	9	131	2007
JOURNAL OF VOCATIONAL BEHAVIOR	9	317	2000
PROCEEDINGS OF THE ROYAL SOCIETY B: BIOLOGICAL SCIENCES	9	839	2001

ANIMAL BEHAVIOUR	7	210	2000
INORGANIC CHEMISTRY	7	302	2005
JOURNAL OF CAREER DEVELOPMENT	6	58	2013
BMJ OPEN	5	72	2012

Note: Table prepared by authors with information recovered from Bibiliometrix software analysis.

Another interesting analysis is to identify the institutions with high production. This data allows to verify laboratories and research groups on a theme. Table 4 shows this data regarding all documents' co-authors. Hebrew University of Jerusalem (38) is the most active institution among publications' co-authors. We were able to identify that 21 of these articles are from researchers in the Department of Psychology. It should be noted that this number may be even higher since we found in our database 10 other publications from this university in which the department of origin of the co-author was not identified.

Table 4

Most Relevant Affiliations

Affiliation	Articles
HEBREW UNIVERSITY OF JERUSALEM	38
UNIVERSITY OF CALIFORNIA	24
UNIVERSITY COLLEGE LONDON	15
UNIVERSITY OF TORONTO	14
UNIVERSITY OF BRITISH COLUMBIA	11
UNIVERSITY OF MICHIGAN	
UNIVERSITY OF MANCHESTER	10
UNIVERSITY OF MINNESOTA	
UNIVERSITY OF SOUTH FLORIDA	
DUKE UNIVERSITY	9
UNIVERSITY OF AMSTERDAM	
UNIVERSITY OF OTTAWA	

Note: Table prepared by authors with information recovered from Bibiliometrix software analysis.

The most cited documents are shown in Table 5 with the number of citations and the average number of citations per year. These articles deal with different approaches to complexity and decision making, emphasizing the multidisciplinarity in which these two topics are researched, such as human resources, mathematics, human and animal behavior, public health, biology, and medicine.

These documents discuss the adaptation of leadership to the complexity of the circumstance (Snowden & Boone, 2007); multicriteria decision problems in complex numbers (Yager & Abbasov, 2013); the effects of complexity on the consistency of the choice (DeShazo & Fermo, 2002); children's mathematical strategies choices (Geary et al., 2004); positive affect in complex decision making (Isen, 2001); evaluation of health promotion programs (Glasgow et al., 2006); task complexity in consumer choice (Swait & Adamowicz, 2001); choice of partner (Landry et al., 2001); influence of environment in complex tasks (Speier et al., 2003); and treatment discussion between doctors and patients (Frosch et al., 2012).

Table 5

Most Cited Articles

Authors/Year	Total Citations	Total Citations per Year
Snowden & Boone (2007)	504	33,6
Yager & Abbasov (2013)	450	50
DeShazo & Fermo (2002)	373	18,65
Geary et al. (2004)	343	19,05
Isen (2001)	331	15,76

Glasgow et al. (2006)	304	19
Swait & Adamowicz (2001)	301	14,33
Landry et al. (2001)	270	12,85
Speier et al. (2003)	269	14,15
Frosch et al. (2012)	256	25,6

Note: Table prepared by authors with information recovered from Bibiliometrix software analysis.

4.2 Conceptual structure and evolution

This section examines how the conceptual framework of research involving decision making and complexity is constituted. For this purpose, the main research themes are described and their evolution over the years is highlighted. The word cloud formed with the authors' keywords are shown in Figure 3. These words are conceptual groups of different topics approached in the studies of the main themes' complexity and decision-making. Important topics were difficulties and indecision in career decision making, mate choice, uncertainty, shared decision making, limited rationality, ethics, complex systems and decision support systems.

Figure 3

Word Cloud

Note: Figure recovered from Bibiliometrix software analysis.

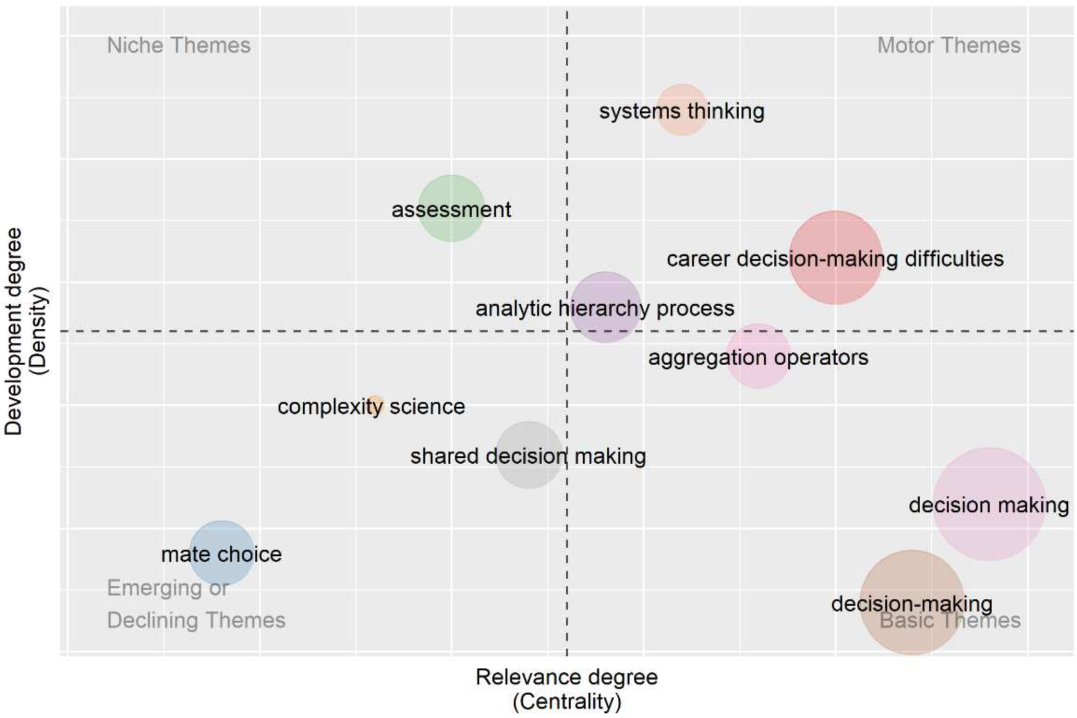
Based on the proposition of Cobo et al. (2011) the thematic maps (Figure 4) show the evolution of a research field from a map with domain's typological themes. It shows a themes network and their relationships which represent the conceptual space of a field's cognitive structure (Zupic & Čater, 2015). We chose using the keywords indicated by the authors as a unit of analysis. The clusters were drawn from the co-word analysis based on the full-time period from 2000 to 2020. We used the main 200 keywords from the set of documents, building the clusters based on words that had a minimum frequency of 3. Each cluster was represented by a main word, and it is classified according to centrality – that measures the importance of the theme – and density – that measures the development of the theme.

The graph consists of four parts. In the upper right quadrant (motor themes) are the themes that have both high density and centrality. This means they are well developed and essential in the research structure (Bibliometrix, 2021). The cluster on career decision making (centrality = 10; density = 8) was promoted in the data set analyzed by renowned researchers such Gati. This has a profound relationship with data from the most frequent sources (Table 5) and most relevant Affiliations (Table 4). Itamar Gati is professor emeritus in the Department of Psychology at The Hebrew University of Jerusalem (Jerusalem, IL) and research career decision making, involving aspects such as improvement, difficulties, and compromises. He is the author with the largest number of publications in our data with 26 articles and 8 of them published in the Journal of Career Assessment. This is reflected in the cluster's size, represented by the scale of the circle, as well as by its importance and development degree, represented by its position on the figure.

The systems thinking cluster (centrality = 12; density = 3) is the most important because it has greatest centrality. In this cluster are topics such as cognitive complexity, oncology, and self-efficacy. Cognitive complexity, for example, is treated in the literature in two ways: as the complexity of the decision that must be made (Crowder-Meyer et al., 2020) or under the cognitive architecture, understood as the complexity of the reasoning employed (Moore & Tenbrunsel, 2014; Stanovich, 2013; Iederan et al., 2009). These different approaches to complexity corroborate with the information presented in the theoretical background session, where we discussed the different views and modes of complexity addressed in the decision-making literature (e.g.: Simon, 1962; Campbell, 1988; Wood, 1986; Liu & Li, 2012; Hærem et al., 2015). Analytic hierarchy process (centrality = 7; density = 7) is another cluster on the motors themes, with discussions mainly on decision support, multicriteria decision making and complex systems.

In the lower right quadrant (basic themes) are themes with low density but high centrality. These themes concentrate a large number of research and constitute the basis of the field (Bibliometrix, 2021). The themes with the highest density are the variations: decision making (centrality = 12; density = 3) and decision-making (centrality = 11; density = 1). This result was widely expected since the field of decision making is one of the pillars of our research. In these clusters are common discussions such as complexity of choice, heuristics, shared decision making, complexity and difficulty of the task, uncertainty, limited rationality, risk, information processing and problem solving.

Figure 4
Thematic Map



Note: Figure recovered from Bibiliometrix software analysis.

In addition to these, more specific research areas in certain fields stand out in these two clusters. Management is one of these themes and in general has its foundations in the field of administration and business. Another keyword highlighted was computational complexity, which is a mapping of the computational resources needed to solve a problem depending on the size of the input (Bossaerts & Murawski, 2017). Complexity theory is also part of these cluster. As discussed above, complexity theory encompasses a multidisciplinary approach between biology, social sciences, mathematics, and physics.

In this quadrant is also the aggregation of operations cluster (centrality = 9; density = 6). It is a very solid cluster and the concepts that make it up are strongly related to each other. The keywords are aggregation operators, complex intuitionistic fuzzy set, mcdm (which is the acronym for multi-criteria decision making), topsis (acronym for technique for order preference by similarity to ideal solution), multi-attribute decision making and multicriteria decision-making.

Multicriteria Decision Making is a general approach used in the evaluation of a finite set of alternatives based on criteria with different degrees of importance (see Liao et al., 2020). It is divided into two categories, multi-objective decision making and multi-attribute decision making. In the multi-attribute decision making – which is also part of this clusters – attributes that represent a criterion of each option are analyzed.

When dealing with confusing, ambiguous or incomplete information – which in general represents complexity according to Campbell (1988) e Wood (1986) – fuzzy logic consists of a skillful way of inferring conclusions and generating responses. One of the main fields of application of fuzzy logic is the expert and decision support systems, which are widely used in multi-attribute and multi-criterion decisions. Fuzzy logic's initial proposition was made by Zadeh (1971) from a version of the set theory. Thus, the process of aggregating operations consists of mathematical operations that convert multiple input values into a single output (see Garg & Rani, 2019). TOPSIS is a fuzzy logic algorithm built for multi-attribute decision making with the main idea that optimal alternative should be the shortest path to the ideal positive solution and the longest distance to the negative ideal solution (Unal & Maleki, 2018).

The lower left quadrant (emerging or declining themes) concentrates themes that have both, low density and centrality. These themes are not strongly developed either because they are new or because they are being left out of the research area (Bibliometrix, 2021). In this quadrant are the clusters created by the themes shared decision making (centrality = 6; density = 4), complexity science (centrality = 4; density = 5) and mate choice (centrality = 2; density = 2). We check in our database the keywords that are part of the shared decision-making cluster (i.e., shared decision-making, children, abortion, and decision aid). They are related to recent publications, usually with a maximum of 10 years. This indicates that the clusters represent a growing topic. Most of these papers are from health's field.

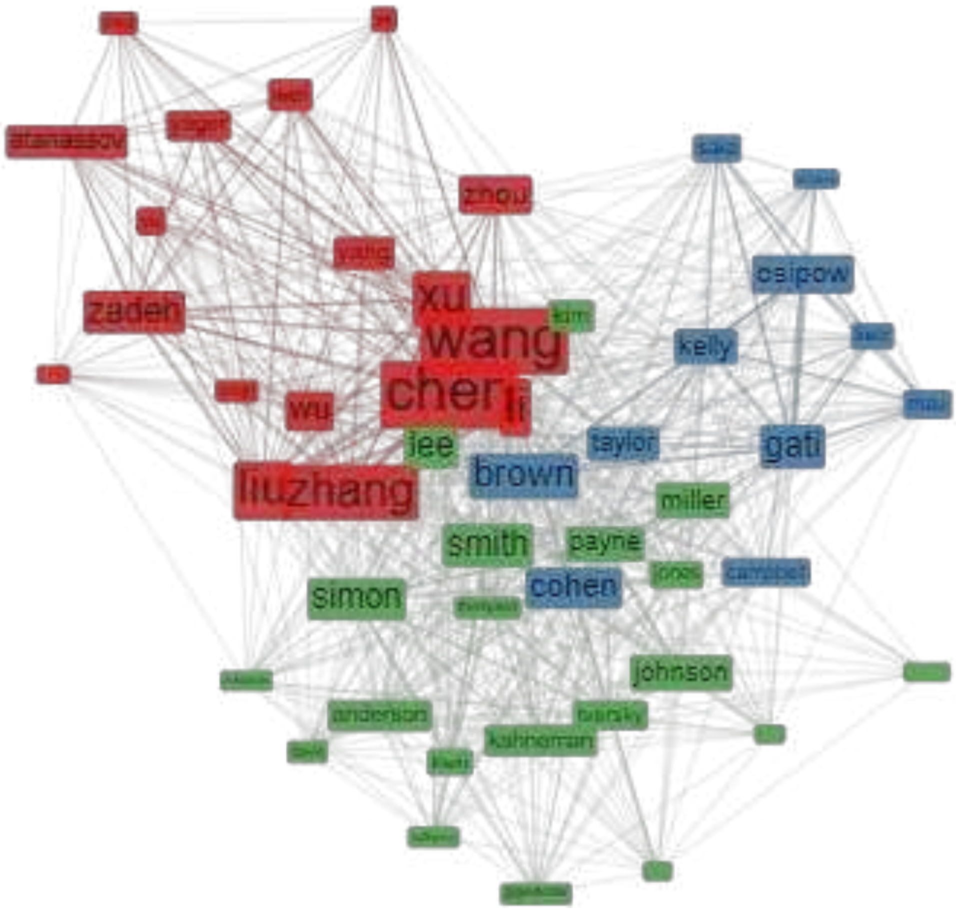
The small cluster of complexity science contemplates only the theme itself. We expected a more expanded approach about the main complexity theme in this cluster, however, the articles focus specifically on health care, especially in patients' lives. This perspective is adopted in studies that investigate decision-making in an intensive care unit (ICU) (de Bock et al., 2018) or under a more managerial view of the human resources in health area (Perez & Liberman, 2011; Shirey et al., 2013). In this quadrant we still have the cluster with less centrality and development: mate choice. It was closer to biology and natural selection. Topics of mate choice, sexual selection and major histocompatibility complex are addressed.

The themes in the upper left quadrant (specialized/niche themes) have high density, but low centrality. This means they are highly developed but isolated, without a great connection with the field of research (Bibliometrix, 2021). The quadrant is composed of the cluster assessment with the following themes: assessment, difficulty index, discrimination index, habitat selection, item response theory, learning, multiple-choice and multiple-choice questions. We understand that this cluster is not particularly representative of our research since it was apparently only formed by common keywords in many studies without characteristic involvement with our topics of interest.

4.3 Knowledge base and intellectual structure

In this session we are concerned with examining the traditions of research involving complexity and decision-making and their interrelationships, based on the basic authors for the field (Zupic & Čater, 2015). Co-citation analysis is an important and widely used technique in bibliometric research. According to Aria and Cuccurullo (2017) it enables to identify the intellectual structure of a scientific field focusing the most cited documents in the article's references. Co-citation occurs when two documents are cited in a publication. Figure 5 present the co-citation network by author. The map was carried out with a minimum degree of co-citation equal to 2 and a threshold of 50 network nodes.

Figure 5
Co-citation Network by Author



Note: Figure recovered from Bibiliometrix software analysis.

Cluster 1 is red. In it are the authors with the greatest centrality of the analysis, such as Chen (betweenness = 69.96; closeness = 0.02), Wang (betweenness = 45.97; closeness = 0.02), Li (betweenness = 37.72; closeness = 0.02) and Xu (betweenness = 31.93; closeness = 0.01). In this cluster the authors work with the complex fuzzy logic presented briefly when we discussed the data of the thematic map (see previously section).

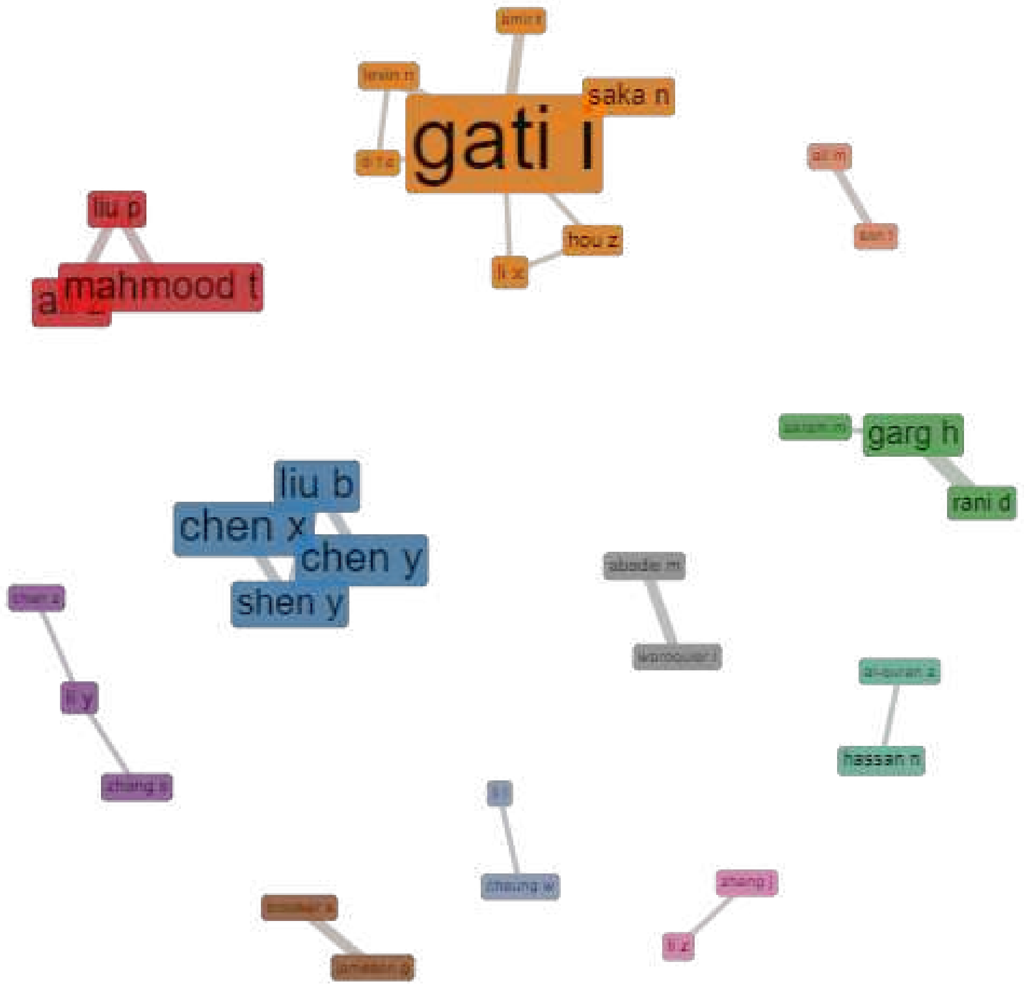
The blue color represents Cluster 2. It is associated in this cluster the work in the career decision-making. The most productive author of our dataset (Itamar Gati) is part of this cluster. The main author of this cluster is Brown (betweenness = 25.95; closeness = 0.019). Duane Brown is a renowned researcher in the field of careers, and who proposed the Values-Based Career Theory.

Cluster 3 (green) presents key authors of the study of behavioral decision-making, such as Simon, Payne, Kahneman, Tversky, Gigerenzer. The main author of this cluster is Lee (betweenness = 14.23; closeness = 0.02) who wrote a classic book on decision theory and human behavior (see Lee, 1971). Herbert Simon (betweenness = 9.82; closeness = 0.01) is also a central author. Simon's importance in the field of decision-making is undoubted. The author won the Nobel Prize in Economics in 1978.

4.4 Social network structure

The social network structure indicates how the relationship is constituted in the researched area (Bibliometrix, 2021). Figure 6 presents authors' collaboration network. We use as parameters the minimum degree of collaboration equal to 2 and the threshold of 50 network nodes. 11 clusters were formed.

Figure 6
Collaboration Network by Authors



Note: Figure recovered from Bibiliometrix software analysis.

Cluster 1 (red) results from the collaboration of Ali, Mahmood and Liu. This collaboration network is formed with 11 articles from our database. These papers involve fuzzy logic and aggregation of operations and are part of the cluster with the name aggregation of operations of the thematic map presented in Figure 7. The aggregation of operations is a basic theme, that is, have a vast number of publications and constitute the pillars of a research area. Looking at our data, we see about 4.3% of the works related to this theme, which can be considered a high percentage, since the thematic map showed several themes involved in research on complexity in decision making.

Cluster 2 (blue) is the one with research in multi-attribute decision making. The MADM and MCDM were also part of the cluster of operations aggregations in the thematic map, once that fuzzy logic is used to deal with complex information which is common in multi-attribute and multi-criterion decision-making. However, in Figure 10 the blue cluster appears separate from the red cluster. This stems from research focuses: while the research on the red cluster is focused on modeling, the research on the blue cluster seeks to understand decision-making from a human-behavioral perspective.

In Cluster 3 (green) the authors also research in the area of fuzzy logic and aggregation of operations, however, they do not publish together with the other authors previously treated. The same fact was revealed for Cluster 4 (purple). This shows that there is no collaboration between authors from different research groups on this topic.

The Cluster 5 is the orange one and it features the largest number of collaborating authors. This cluster reflects research involving career decision making. The main author is Gati (betweenness = 13; closeness = 0.0012) who is also the most central author of the entire network (see box size). In Cluster 6 (brown) does not have much importance in our network. In it are authors who research on the complexity of materials and chemical compounds. Cluster 7 (pink) involves collaboration in work on the basic theme of decision making, investigating big data related to internet shopping and the study of unplanned decision making, such as in emergency situations.

Cluster 8 is gray and brings studies on complex decision making and the use of awareness, deliberation and weighting of information. This cluster involves researching information processing. Cluster 9 (light blue, lower region of the figure) is formed by researchers who collaborate in the investigation of soft computing, treatability, and reduced costs of solving problems with high imprecision and uncertainty. Cluster 10 (salmon) is formed by works that use the neutrosophic set as a tool for modeling uncertainty in decision making. The neutrosophic set is a formal framework that generalizes the concepts of fuzzy logic, as Clusters 1, 2, 3 and 4. Finally, Cluster 11 (dark gray), formed by the authors Li L and Cheung W also deals with the area of chemistry.

5 CONCLUSIONS

Employing bibliometric analysis for scientific mapping on a dataset of 1,352 academic articles, we have been able to identify major development in the research involving decision-making and complexity over years between 2000 and 2020. We divided our discussion into four sections: the general descriptive analysis, the conceptual structure, the intellectual structure and the social network structure. But looking at our results, we understand that many conclusions take into account precisely the relationship between these different analyzes.

In terms of growth rate, the annual growth rate of scientific production relating these two topics together is 12.12%. The last 5 years of our timespan (2015-2020) compile 40% of the total articles. This linear growth rate and the concentration of a significant amount in the last 5 years allows us to conclude that research involving complexity and decision making are still important, pointing out that this is still a profitable field and with space for further discussions, as we already had identified in our theoretical background session. This encourages us and other researchers for future research.

We had discussed in the theoretical background the evidence pointed out by Rescher (1998) that the multidisciplinarity of studies, the definition of theoretical concepts and distinct measures in each field brings complexity to the study of complexity. In addition, authors of complexity in human behavioral decision-making (Campbell, 1988; Liu & Li, 2012; Hærem et al., 2015) underline the same direction, indicating confusions between complexity vs. difficulty and in understanding the properties of the construct and its operationalization. We suggest that research can be carried out to verify how the complexity construct was operationalized in investigations in decision making. Our results confirmed the multidisciplinary nature of the research. In the analysis of the conceptual structure, the thematic map shows vastly different themes with our search words. Additionally, we discussed the system thinking's cluster that has different approaches about complexity, as previously presented by authors (Simon, 1962; Campbell, 1988; Wood, 1986; Liu & Li, 2012; Hærem et al., 2015) discussed in our theoretical background session.

The importance of research on career decision making became very evident. This finding was driven by descriptive data as most active institution (Hebrew University of Jerusalem). It was also corroborated by the analysis of the conceptual structure (word cloud and thematic map) and social network structure (collaboration network between authors). In these parts of our results session, we discuss the robustness of the theme of career decision making. As in the thematic map this research topic is a motor theme, we can conclude this is a well-developed theme and it is essential in the research dynamics involving complexity and decision making. In addition to this result, in the co-citation analysis the cluster referring to the theme of career decision making was the one that presented an extremely high strength of association between its nodes. Other research themes highlighted were fuzzy logic and multi-criteria decision making. These themes are related in different ways and are used under different approaches. Among the multi-criteria methods, AHP is the most prominent.

On the other hand, there are research topics that are still growing. Shared decision making is in the emerging or declining themes quadrant on the thematic map. However, we understand that this is a growing field because most research has less than 10 years old. From this we can conclude that there may be room for research in areas other than health - the main area found in our sample.

We present some main conclusions based on the discussions from the previous session. We understand that some limitations should be highlighted. The choice of terms and the option for not limiting the databases' area to management and business resulted in a very expanded search and some publications are far from our original area of investigation. To overcome this limitation, we suggest future works consider including another field title to identify the area or scientific field of interest or when the databases allow it, filtering publications by areas should be used. Another limitation stems from the choice of databases, which can be expanded in future research to cover a greater number of publications. The same can be done with respect to the timespan. Future research may also seek to understand how modes of complexity (Rescher, 1998; presented in Table 1) are operationalized in studies. As well as identifying how New Assumptions (Hærem et al., 2015) are being addressed in current research.

REFERENCES

Adami, C. (2002). What is complexity?. BioEssays, 24(12), 1085-1094. https://doi.org/10.1002/bies.10192

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of informetrics, 11(4), 959-975. https://doi.org/10.1016/j.joi.2017.08.007

Bibliomerix. (3.0.5) (2021). A brief introduction to bibliometrix [Web page]. Retrieved from https://www.bibliometrix.org/vignettes/Introduction_to_bibliometrix.html

Bossaerts, P., & Murawski, C. (2017). Computational complexity and human decision-making. Trends in Cognitive Sciences, 21(12), 917-929. https://doi.org/10.1016/j.tics.2017.09.005

Campbell, D. J. (1988). Task complexity: A review and analysis. Academy of management review, 13(1), 40-52. https://doi.org/10.2307/258353

Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application

to the fuzzy sets theory field. Journal of informetrics, 5(1), 146-166. https://doi.org/10.1016/j.joi.2010.10.002
Crowder-Meyer, M., Gadarian, S. K., Trounstine, J., & Vue, K. (2020). A different kind of disadvantage: Candidate race, cognitive complexity, and voter choice. Political Behavior, 42(2), 509-530. https://doi.org/10.1007/s11109-018-9505-1
de Bock, B. A., Willems, D. L., & Weinstein, H. C. (2018). Complexity perspectives on clinical decision making in an intensive care unit. Journal of evaluation in clinical practice, 24(1), 308-313. https://doi.org/10.1111/jep.12794
DeShazo, J. R., & Fermo, G. (2002). Designing choice sets for stated preference methods: the effects of complexity on choice consistency. Journal of Environmental Economics and management, 44(1), 123-143. https://doi.org/10.1006/jeem.2001.1199
Ferreira, J. J. M., Fernandes, C. I., & Ratten, V. (2016). A co-citation bibliometric analysis of strategic management research. Scientometrics, 109(1), 1-32. https://doi.org/10.1007/s11192-016-2008-0
Franco, J. P., Yadav, N., Bossaerts, P., & Murawski, C. (2020). Structural properties of individual instances predict human effort and performance on an NP-Hard problem. bioRxiv, 405449.
Frosch, D. L., May, S. G., Rendle, K. A., Tietbohl, C., & Elwyn, G. (2012). Authoritarian physicians and patients' fear of being labeled 'difficult'among key obstacles to shared decision making. Health affairs, 31(5), 1030-1038. https://doi.org/10.1377/hlthaff.2011.0576
Geary, D. C., Hoard, M. K., Byrd-Craven, J., & DeSoto, M. C. (2004). Strategy choices in simple and complex addition: Contributions of working memory and counting knowledge for children with mathematical disability. Journal of experimental child psychology, 88(2), 121-151. https://doi.org/10.1016/j.jecp.2004.03.002
Glasgow, R. E., Klesges, L. M., Dzewaltowski, D. A., Estabrooks, P. A., & Vogt, T. M. (2006). Evaluating the impact of health promotion programs: using the RE-AIM framework to form summary measures for decision making involving complex issues. Health education research, 21(5), 688-694. https://doi.org/10.1093/her/cyl081
Garg, H., & Rani, D. (2019). Novel aggregation operators and ranking method for complex intuitionistic fuzzy sets and their applications to decision-making process. Artificial Intelligence Review, 1-26. https://doi.org/10.1007/s10462-019-09772-x
Hærem, T., Pentland, B. T., & Miller, K. D. (2015). Task complexity: Extending a core concept. Academy of management review, 40(3), 446-460. https://doi.org/10.5465/amr.2013.0350
Iederan, O. C., Curşeu, P. L., & Vermeulen, P. (2009). Effective decision-making: The role of cognitive complexity in strategic decisions. Studia Psychologica, 51(4), 293-304.
Isen, A. M. (2001). An influence of positive affect on decision making in complex situations: Theoretical issues with practical implications. Journal of consumer psychology, 11(2), 75-85. https://doi.org/10.1207/S15327663JCP1102_01
Landry, C., Garant, D., Duchesne, P., & Bernatchez, L. (2001). 'Good genes as heterozygosity': the major histocompatibility complex and mate choice in Atlantic salmon (Salmo salar). Proceedings of the Royal Society of London. Series B: Biological Sciences, 268(1473), 1279-1285. https://doi.org/10.1098/rspb.2001.1659
Lee, W. (1971). Decision theory and human behavior (No. 153.83 L4).
Liao, H., Wu, X., Mi, X., & Herrera, F. (2020). An integrated method for cognitive complex multiple experts multiple criteria decision making based on ELECTRE III with weighted Borda rule. Omega, 93, 102052. https://doi.org/10.1016/j.omega.2019.03.010
Liu, P., & Li, Z. (2012). Task complexity: A review and conceptualization framework. International Journal of Industrial Ergonomics, 42(6), 553-568. https://doi.org/10.1016/j.ergon.2012.09.001

Michalski, J., Green, A. M., & Cisek, P. (2020). Reaching decisions during ongoing movements. Journal of neurophysiology, 123(3), 1090-1102. https://doi.org/10.1152/jn.00613.2019
Moore, C., & Tenbrunsel, A. E. (2014). "Just think about it"? Cognitive complexity and moral choice. Organizational Behavior and Human Decision Processes, 123(2), 138-149. https://doi.org/10.1016/j.obhdp.2013.10.006
Perez, B., & Liberman, A. (2011). Toward the adoption of complexity science in health care: Implications for risk-taking and decision-making activities. The health care manager, 30(1), 71-85. https://doi.org/10.1097/HCM.0b013e3182078be9
Pritchard, A. (1969). Statistical bibliography or bibliometrics. Journal of documentation, 25(4), 348-349.
Ramchandran, K., Fiedorowicz, J., Chen, Z., Bu, Y., Bechara, A., & Andreasen, N. C. (2020). Patients on the psychosis spectrum employ an alternate brain network to engage in complex decision-making. PloS one, 15(9), e0238774. https://doi.org/10.1371/journal.pone.0238774
Rescher, N. (1998). Complexity: A philosophical overview. Transaction Publishers.
Simon, H. A. (1955). A behavioral model of rational choice. The quarterly journal of economics, 69(1), 99-118. https://doi.org/10.2307/1884852
Simon, H. A. (1962). The architecture of complexity. Proceedings of the American Philosophical Society, 106(6), 467-482.
Speier, C., Vessey, I., & Valacich, J. S. (2003). The effects of interruptions, task complexity, and information presentation on computer-supported decision-making performance. Decision sciences, 34(4), 771-797. https://doi.org/10.1111/j.1540-5414.2003.02292.x
Stanovich, K. E. (2013). Why humans are (sometimes) less rational than other animals: Cognitive complexity and the axioms of rational choice. Thinking & Reasoning, 19(1), 1-26. https://doi.org/10.1080/13546783.2012.713178
Swait, J., & Adamowicz, W. (2001). The influence of task complexity on consumer choice: A latent class model of decision strategy switching. Journal of Consumer Research, 28(1), 135-148. https://doi.org/10.1086/321952
Saaty, T. L. (1990). An exposition of the AHP in reply to the paper "remarks on the analytic hierarchy process". Management science, 36(3), 259-268. https://doi.org/10.1287/mnsc.36.3.259
Snowden, D. J., & Boone, M. E. (2007). A leader's framework for decision making. Harvard business review, 85(11), 68.
Shirey, M. R., Ebright, P. R., & McDaniel, A. M. (2013). Nurse manager cognitive decision-making amidst stress and work complexity. Journal of Nursing Management, 21(1), 17-30. https://doi.org/10.1111/j.1365-2834.2012.01380.x
Unal, O., & Maleki, E. (2018). Shot peening optimization with complex decision-making tool: Multi criteria decision-making. Measurement, 125, 133-141. https://doi.org/10.1016/j.measurement.2018.04.077
Wood, R. E. (1986). Task complexity: Definition of the construct. Organizational behavior and human decision processes, 37(1), 60-82. https://doi.org/10.1016/0749-5978(86)90044-0
Yager, R. R., & Abbasov, A. M. (2013). Pythagorean membership grades, complex numbers, and decision making. International Journal of Intelligent Systems, 28(5), 436-452. https://doi.org/10.1002/int.21584
Zadeh, L. A. (1971). Similarity relations and fuzzy orderings. Information sciences, 3(2), 177-200. https://doi.org/10.1016/S0020-0255(71)80005-1
Zupic, I., & Čater, T. (2015). Bibliometric methods in management and organization. Organizational Research Methods, 18(3), 429-472. https://doi.org/10.1177/1094428114562629