Mapping the Intellectual Structure of Uncertainty Research in Decision Science and Management: A Keyword Co-Occurrence Network Analysis

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ABSTRACT

Uncertainty is an important and frequent concept in decision science and management. It influences how researchers consider risks, take decisions and improve the adaptability of organizations. Although much research has been conducted, the interdisciplinary framework linking different fields of uncertainty is still in a divided condition. These disciplines include classical decision theory, behavioral economics and practical environmental management. In this review, bibliometric network mapping is applied to show and analyse the co-occurrence of keywords related to the idea of "uncertainty" in the decision science and management literature. By analysing the resultant keyword co-occurrence network, four major themes are found: 1. Methodological and modelling methods such as multi-criteria decision analysis, optimization and system approach. 2. Theoretical bases of classical decision theory like expected utility, entropy and decision-making under uncertainty. 3. Behavioural and risk-related aspects such as risk, ambiguity, heuristics, judgment and rationality. 4. Practical management and sustainable conditions like deep uncertainty, climate change, policy and trust. The prominent positions and sizes of the nodes representing "uncertainty", "decision-making", "risk", "model" and "decision-making" reveal their functions as conceptual links among various sub-fields. We discuss the theoretical and practical effects of this thematic structure and suggest some directions for future integrated research, especially on the intersection of deep uncertainty, adaptive management and behavioural decision theory.

Keywords: Uncertainty; Decision Making; Bibliometric Analysis; Keyword Co-Occurrence; Risk; Decision Science; Management

INTRODUCTION

Uncertainty is an important problem in the study of decision science and management, ranging from the first formalization of decision-making under risk to the current methods handling "deep" and "serious" uncertainties in policy-making and environmental management. Scholars from different areas such as economics, psychology, operations research and organizational studies have tried to understand how individuals and organizations assess, express and take actions concerning insufficient or vague data. Nevertheless, due to the wide variety of branches involved, the related literature has formed a vast and dispersed collection. In this literature, various methodological backgrounds, for example, normative decision theory, behavioral economics, multiple criteria decision analysis and applied risk and policy studies, have generally developed separately from each other.

This division gives rise to a practical problem for researchers and practitioners. It is difficult to locate the fundamental "plan" of the field, to differentiate the important themes from the minor ones, and to understand the relations between the new investigation areas, such as the profound uncertainty in climate adaptation or the representation and communication of uncertainty, and the well-known theoretical foundations like the expected

utility theory and the research on heuristics and biases. A systematic and reproducible method to solve this question is bibliometric network analysis. By examining the co-occurrence of the author-assigned keywords in a great number of documents, it is possible to build up the intellectual structure of a research area by using empirical evidence instead of just descriptive accounts or the opinions of experts.

This review follows a similar approach. A keyword co-occurrence network based on the word "uncertainty" (Fig. 1) is employed to detect the main themes in the decision science and management literature regarding uncertainty. Subsequently, the crucial functions and locations of the major concepts within this system are explained. Finally, the significant relationships shown by the network are discussed.

It is important for two groups of people to grasp this structure. For researchers, a well-defined description of the thematic classifications facilitates their connection with the previous studies and decreases the chance of getting the same results with different terminologies. It also shows the hidden relations between different branches which might be overlooked in the assessment of a single discipline. However, practitioners and policy-makers need to use formal decision-making methods, behavioral knowledge and practical administrative techniques when dealing with uncertainties like climate change adaptation, public health or financial risk management. In this situation, it is beneficial to know the relationships among these various approaches in order to make better decisions and select appropriate methods. Thus, bibliometric mapping is not only a descriptive work but also an evaluating one. It points out the main fields where abundant methodological and theoretical resources exist and those that require further development.

The following sections of this paper are organized as follows. In Section 2, we describe the bibliometric mapping approach used to construct and investigate the network. Section 3 presents the obtained cluster arrangement. Section 4 discusses the theoretical and practical implications of this arrangement and highlights the weak points which indicate possible directions for further research. Lastly, Section 5 concludes.

METHODOLOGY

This remark is based on a keyword co-occurrence network. The keywords come from the peer-reviewed papers which are recorded in a major bibliographic database like Scopus or Web of Science. These papers are obtained by looking for the words "uncertainty" and "decision making" in the title, abstract or keywords. The authors must mention the particular database employed, the exact search formula, the date of the search, the inclusion and exclusion standards, the period of publication and the total number of documents and distinct keywords identified. Additionally, the limitations on the subject areas such as business, management, decision-related fields or social sciences should be defined.

VOSviewer, which is commonly used for constructing and visualizing bibliometric networks (van Eck & Waltman, 2010), was employed to build and display the network. At the initial count, co-occurrence was determined by counting the times two keywords appear together in the same document once, ignoring the number of authors. A certain minimum number of occurrences was set to keep those keywords which appear often enough. Then, the association-strength normalisation method and a clustering algorithm based on modularity were used to categorize the keywords into thematic groups. In the obtained map, the size of each node represents the frequency of keyword occurrence. The distance between nodes indicates the strength of their co-occurrence. The thickness of the edges shows the strength of the co-occurrence link, and the colour of the nodes reveals which group they belong to. It is important that the authors specify the exact minimum-occurrence threshold, the number of keywords satisfying this condition, the number of identified clusters and any manually combined synonymous terms (e.g., 'decision making' and 'decision-making').

In Section 3, the analysis given is based on a visual and thematic study of the generated network diagram. This study includes the colour of clusters, the frequency of nodes, the importance of nodes and the semantic meaning of the key terms in each cluster. This qualitative analysis is a common method in bibliometric evaluations. Its aim is to add to, not replace, the quantitative network indices such as the total connection strength and prominence between nodes. The authors should include these indices along with the diagram in the final manuscript.

Results: Structure of the Uncertainty Research Network

The network of keyword co-occurrences is mainly composed of some very frequent and important terms. Among them, "uncertainty", "decision-making processes", "decision-making", "risk" and "model" are the most prominent. The big sizes of their nodes indicate their role as basic concepts which connect the four major theme groups of the network (Fig. 1). Now, each group will be discussed individually.

Cluster 1 — Methodological and Modeling Approaches

The first cluster shown in green is mainly about the "model" concept, including some key terms such as analytic hierarchy process (AHP), choice, blueprinting, refinement, guidelines, systems, approach and architecture. In fact, this cluster refers to the background of operations-research and multi-criteria decision analysis (MCDA) in uncertain studies. Here, we develop formal models and structured methods, for instance, the AHP, refinement algorithms and guided selection procedures, to help in decision-making when the results or preferences are not completely clear. The existence of "architecture", "systems" and other technical words like "refinement" indicates that this cluster involves both the construction of formal decision-support tools and their application in wider organizational or system-level frameworks.

Cluster 2 — Classical Decision-Theoretic Foundations

The second group, represented by yellow or olive, is connected with "decision making" and involves concepts such as entropy, utility, representation and visualization. This group reflects the normative and information-theoretical aspects of the subject. Entropy is an important concept from information theory and utility is a fundamental part of expected utility theory. Moreover, "representation" and "visualization" show the importance given to how decision-makers convey, pass on and understand uncertainty. The presence of both traditional and modern terms in this group indicates the close relationship between the original formal decision theory and the current research on representing and visualizing uncertainty for practical decision-making.

Cluster 3 — Behavioral and Risk Dimensions

The third cluster, which is colored in red or orange, is the most dense one in the network. It mainly concerns the idea of "risk" and its related keywords such as choice, anticipated utility, likelihood, vagueness, inclinations, conduct, assessment, mental shortcuts, limited rationality and avoiding vagueness. This cluster is closely related to the study on behavioral decision-making and judgment-decision-making (JDM). In these investigations, traditional normative theories, like anticipated utility and likelihood, are combined with descriptive psychological facts such as mental shortcuts, limited rationality and avoidance of vagueness. The larger size of the nodes representing "risk", "choice" and "vagueness" indicates that they are among the most discussed topics in the relevant literature. Their connection to "assessment" and "mental shortcuts" suggests the continuous influence of the heuristic-bias research on the analysis of decisions under uncertain conditions.

Cluster 4 — Applied Management and Sustainability Contexts

The fourth group, in blue color, mainly deals with "management" and "decision-making." It comprises elements such as resilience, help, deep uncertainty, adaptation, climate change, protection, scientific knowledge, policy formulation, decision evaluation, perfection, communication, confidence and worry. This group is connected to the use of uncertainty concepts in real management and policy issues, especially in environmental and natural resources management. The coexistence of "deep uncertainty" and "resilience" with "climate change," "protection" and "policy" indicates the increasing effect of strong decision-making and adaptive management approaches when it is not possible to give probability descriptions for uncertainties. The presence of "confidence," "communication" and "worry" shows that this group considers the stakeholders and governance when facing uncertainties. This is opposite to the behavior of the previous group which is mainly concerned with single individuals.

Cross-Cluster Bridging Concepts

Outside of the four clusters, some terms play an important role in connecting the clusters. Among them,

"information", "performance", "impact" and "decision analysis" are located at the intersections of the methodological, behavioural and applied-management clusters. This indicates that although uncertainty research has developed along different methodological and disciplinary directions, there exist considerable relationships. For example, there are links via the use of information-theoretical concepts in both formal modelling and applied management cases. Another instance is the application of decision-analytical techniques from theory to practice.

DISCUSSION

The four-cluster structure found in this study suggests that research on decision science and management concerning uncertainty can be considered as the interaction of three main viewpoints. These viewpoints are the formal/methodological, the behavioral/psychological, and the applied/managerial, which are based on a common conceptual basis including 'uncertainty', 'decision-making' and 'risk'. This framework is consistent with the previously recognized results that the study of decision-making under uncertainty has developed along three parallel routes: normative, descriptive and prescriptive. Normative decision theory (Cluster 2) specifies the ways decisions should be taken when dealing with uncertain information. Descriptive, behavioral research (Cluster 3) describes how decisions are really performed, often differing from the standards proposed by normative theory. Prescriptive, applied decision analysis (Clusters 1 and 4) develops methods and tools intended to assist real-world decision-makers in making correct choices even though there are deviations and difficulties in precisely defining uncertainty.

Theoretical Implications

From a theoretical viewpoint, there is no perfect system to handle uncertainty in this area at present. Several methods are applied together. The relation between "expected utility" and "probability" on one hand and "choice" and "risk" on the other in Cluster 3 indicates that the subjective expected utility theory is still the main normative basis. Most behavioural phenomena, such as the aversion to ambiguity and judgments affected by losses, are generally explained and evaluated based on this theory. However, the differences between the probabilistic aspect and "deep uncertainty" and "robustness" in Cluster 4 reveal a clear distinction in basic concepts. Expected utility and related Bayesian methods suppose that uncertainty can be expressed as a probability distribution. On the contrary, the deep-uncertainty and robust decision-making schemes deny this assumption especially when the possible future states or the proper probability model cannot be determined accurately. Hence, the network diagram provides empirical and structural evidence for the conceptual difference which is often discussed in literature but rarely illustrated graphically.

Practical and Managerial Implications

From a practical viewpoint, clustering plays an important role in determining the selection and integration of decision-support systems. Cluster 1, concentrating on methodology and modelling, and Cluster 4 concerning applied management, are associated mainly through 'frameworks', 'systems' and 'decision analysis', rather than a great many common terms. This connection implies that the formal multiple criteria and optimisation techniques developed in Cluster 1 have not been thoroughly implemented in the practical sustainable and policy scenarios presented in Cluster 4. People dealing with problems such as climate change adaptation or species preservation, which are definitely included in Cluster 4, might use the widely recognised formal multiple criteria decision analysis (MCDA) and optimisation tools from Cluster 1 less frequently than necessary. On the other hand, the developers of these tools may not give enough consideration to the demands of robustness and high levels of uncertainty which are significant in applied environmental and policy fields. A feasible method to promote methodological progress with immediate practical advantages is to intentionally connect these two clusters, for instance, by explicitly incorporating robustness criteria in decision-support tools based on Analytic Hierarchy Process (AHP) or optimisation.

A great many significant conclusions can be drawn from this model. Firstly, the significance of expected utility, probability, entropy and some new concepts such as vagueness, vagueness aversion (based on the definition of vagueness) and rules of thumb regarding vagueness still exists, which implies that the traditional normative theories are still useful for explaining the present behavioral deviations. Although the scope of behavioral research has been considerably widened, this situation still persists. Secondly, the appearance of 'profound

uncertainty', 'resilience' and 'adjustment' as a new issue in the applied management field signifies a more profound change in this area. It moves from mainly applying probability-based methods to handle uncertainties to using frameworks like resilient decision-making and adaptive management. These frameworks are suitable for situations where the probability distributions of future states cannot be determined exactly. This transition is especially apparent in the relation between 'profound uncertainty' and practical fields such as climate change and conservation. In these areas, the inherent uncertainty in the future conditions has a notable impact on the decision-making process.

Furthermore, the presence of words such as “visualization”, “representation”, “communication” and “trust” which can be found in the network shows an increasing interest in the communicative aspect of uncertainty concerning human interactions. It implies that attention is paid not only to the modelling of uncertainty or the real reaction of decision-makers to it, but also to the presentation and communication of it in order to build appropriate levels of confidence and trust among the participants. This topic may act as a bridge between the classical decision-theoretic group and the applied management group. It may be a promising field for further integrated research, particularly because decision-support systems and data visualization tools become more important in the organizational and policy-making procedures.

Finally, the "sets" (which might be understood as fuzzy set theory) is a little but historically significant approach - describing uncertainty through fuzzy and possibilistic systems rather than definite probabilistic methods. Although this secondary issue is not closely connected to the four major categories in the present system, it has affected the multiple criteria decision-making methods such as Analytic Hierarchy Process (AHP) throughout history. It may also require a broader combination with the study on robust and deep uncertainty in Cluster 4.

Directions for Future Research

According to the results, there are at least four directions for further study. First, it is possible to carry out a more thorough combination between the behavioral/risk category and the applied management category. For example, we can better integrate the well-known heuristics and biases into the design of the decision-making and adaptive-management systems used in climate and conservation policies. This will enable these systems to consider not only the structural uncertainty of the environment but also the obvious systematic biases people have when dealing with uncertainty. Secondly, the sub-theme of visualization and communication, which has been identified previously, should receive more systematic development as an independent research field. This is particularly important considering the increasing availability of interactive and AI-assisted decision-support tools which can dynamically show the uncertainty to the non-expert participants. The effect of such visual representations on the trust, confidence and the quality of the subsequent decisions is still not fully explored in comparison with the whole category of behavioral studies.

Furthermore, linking probabilistic techniques (e.g., expected utility and entropy) with non-probabilistic ones (such as fuzzy sets, deep uncertainty and robustness) may help to integrate the current separate sections in the literature of Clusters 1 and 4. Combining for example, fuzzy multiple criteria methods with robust decision-making ideas is an interesting but still limited field within the studied network. Additionally, as this study is based on a single and static perspective of the literature, further research should consider a clear longitudinal or overlaid analysis. This analysis should follow the change of cluster composition, keyword importance and inter-cluster relationships through successive time periods. The aim is to discover whether the area is tending towards more integration among the formal, behavioral and applied-management traditions mentioned, or if these traditions will mainly develop separately.

These results should be taken into account considering the limitations of the keyword co-occurrence method. As this technique relies on the keywords given by the authors, it is prone to the misuse of keywords. For example, in the present network, "decision making" and "decision-making" are treated as two different nodes. Furthermore, it cannot fully express the semantic information or theoretical points of each paper. Therefore, the view presented here should be viewed as a structural and exploratory study of the arrangement of themes in the field. It is suggested to further analyze the key papers in each cluster with a detailed reading. In addition, it is advisable to give a complete explanation of the search strategy, the database utilized and the clustering parameters on which the network is based.

CONCLUSION

In this test, a keyword co-occurrence network analysis was used to describe the research framework on uncertainty in decision science and management. Four related themes were found: methodological/modeling, classical decision-theoretic, behavioral/risk and applied management/sustainability. All these clusters focus on the main concepts of uncertainty, decision-making and risk. The constructed map shows that although the discipline has methodological diversity, it still has a common conceptual basis. It also points out some promising directions for further integrated studies, particularly on the intersection of deep uncertainty, flexible decision-making and the presentation of uncertainty to decision-makers and stakeholders. For future bibliometric research, it is recommended to include comprehensive quantitative reports (such as search methods, sample characteristics and network statistics). Furthermore, it would be useful to add a systematic qualitative evaluation of the most frequently cited papers in each identified theme.

Figure 1

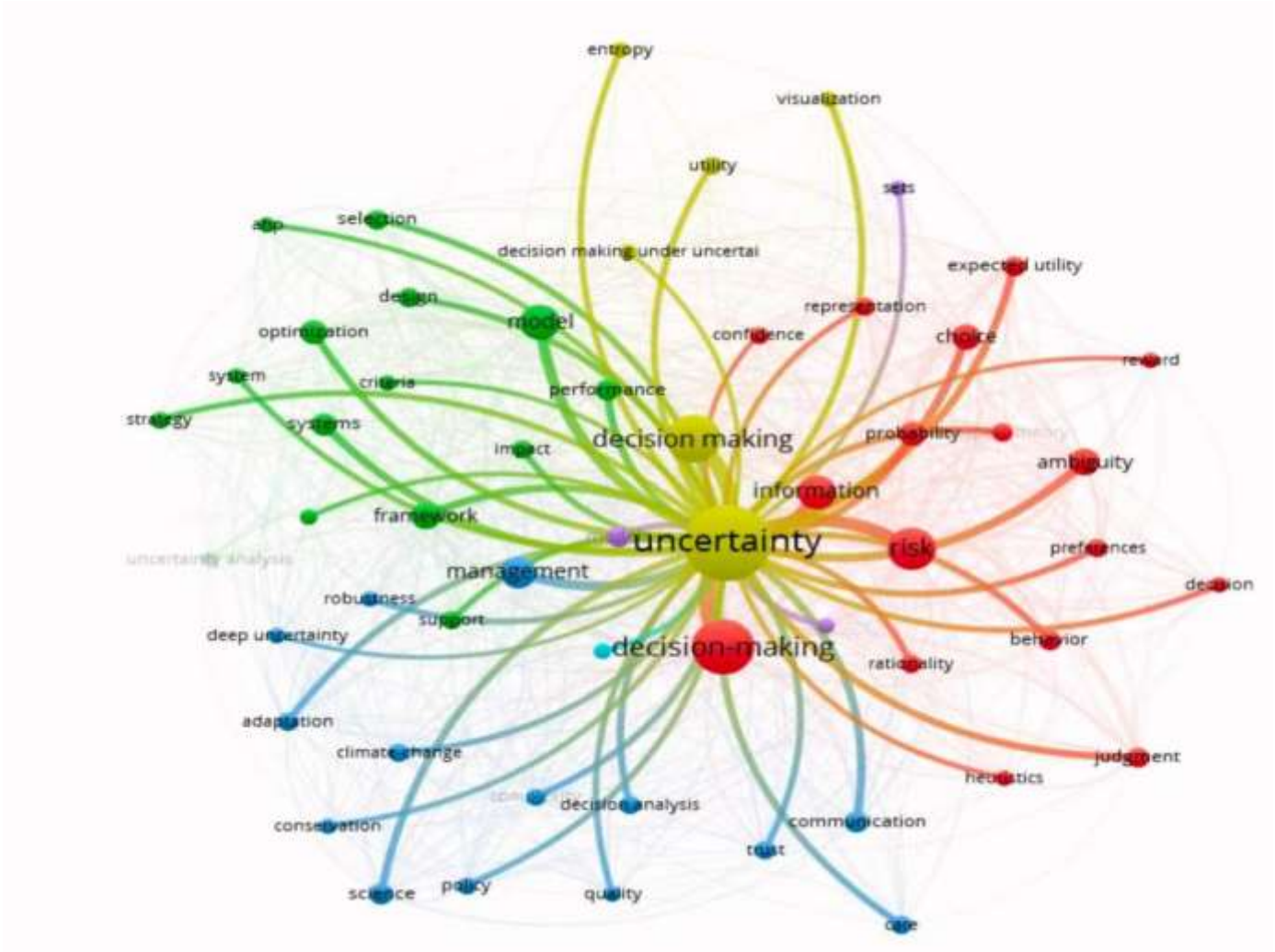

Figure 1. Keyword co-occurrence network of the decision-science and management literature on uncertainty. Node size reflects keyword frequency; node color denotes cluster membership; edge thickness reflects co-occurrence strength. [Insert software name/version and network parameters in the caption per journal style.]

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