UNIVERSIDADE FEDERAL DE CAMPINA GRANDE

UNIDADE ACADÊMICA DE ADMINISTRAÇÃO E CONTABILIDADE

PROGRAMA DE PÓS-GRADUAÇÃO EM ADMINISTRAÇÃO

A FACILITATION MODEL BASED ON SOFT SYSTEMS METHODOLOGY TO SUPPORT DECISION MAKING IN BRAZILIAN WATERSHED COMMITTEES

DISSERTAÇÃO DE MESTRADO

ALEXANDRE DE ARAÚJO GOMES JÚNIOR

CAMPINA GRANDE – PB, 2021

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Orientadora: Profa. Dra. Vanessa Batista Schramm

Dissertação apresentada como pré-requisito para obtenção do grau de Mestre em Administração do Programa de Pós-Graduação em Administração da Universidade Federal de Campina Grande.

CAMPINA GRANDE – PB, 2021

G633f Gomes Júnior, Alexandre de Araújo.
A facilitation model based on soft systems methodology to support decision making in brazilian watershed committees / Alexandre de Araújo Gomes Júnior. – Campina Grande, 2021.
128 f. : il. color.

Dissertação (Mestrado em Administração) – Universidade Federal de Campina Grande, Centro de Humanidades, 2021.
"Orientação: Profª. Drª. Vanessa Batista Schramm".
Referências.

1. Problem Structuring Methods. 2. Soft Systems Methodology. 3. Complex Problems. 4. Facilitation Model. 5. Watershed Committees. I. Schramm, Vanessa Batista. II. Título.

CDU 004.41(043)

FICHA CATALOGRÁFICA ELABORADA PELA BIBLIOTECÁRIA MARIA ANTONIA DE SOUSA CRB 15/398

MINISTÉRIO DA EDUCAÇÃO
UNIVERSIDADE FEDERAL DE CAMPINA GRANDE
POS-GRADUACAO EM ADMINISTRACAO
Rua Aprígio Veloso, 882, - Bairro Universitário, Campina Grande/PB, CEP 58429-900

FOLHA DE ASSINATURA PARA TESES E DISSERTAÇÕES

ALEXANDRE DE ARAÚJO GOMES JÚNIOR

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Dissertação apresentada ao Programa de Pós-Graduação em Administração (PPGA-UFCG) como pré-requisito para obtenção do título de Mestre em Administração.

Aprovado em: 22/02/2021

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Examinador Externo

Campina-Grande-PB, 2021

Documento assinado eletronicamente por **KETTRIN FARIAS BEM MARACAJA**, **PROFESSOR(A) DO MAGISTERIO SUPERIOR**, em 22/02/2021, às 10:01, conforme horário oficial de Brasília, com fundamento no art. 8º, caput, da Portaria SEI nº 002, de 25 de outubro de 2018.

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Documento assinado eletronicamente por **Mischel Carmen Neyra Belderrain**, **Usuário Externo**, em 22/02/2021, às 15:47, conforme horário oficial de Brasília, com fundamento no art. 8º, caput, da Portaria SEI nº 002, de 25 de outubro de 2018.

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Referência: Processo nº 23096.002029/2021-42 SEI nº 1292230

Dedico este trabalho a Deus, “porque dEle e por Ele, e para Ele, são todas as coisas; glória pois a Ele eternamente. Amém.” Romanos 11:36.

AGRADECIMENTOS

O início deste curso de mestrado realmente não foi fácil para mim, é bom que isso fique registrado, mas o processo foi felizmente prazeroso e de grande aprendizado e, agora, concluo-o com sentimento de imensa alegria. Dito isso, vamos aos agradecimentos.

Primeiramente, toda honra e toda glória a Jesus Cristo, meu redentor, agradeço-lhe suas infinitas graça e misericórdia.

A minha família, minha mãe e minha irmã, o apoio, a dedicação, os esforços e, principalmente, as orações. Sem minha mãe, seria impensável, quiçá impossível, chegar neste ponto. Tudo o que foi plantado desde a infância está começando a render frutos. Portanto, sou imensamente grato.

À duas pessoas mais que especiais na minha vida. À Rayane, que conheci há sete anos no início da graduação, mas que nos aproximamos apenas agora no mestrado, a sua alegria, as conversas diárias, as risadas, o apoio e os incentivos. E à Marília, que seguiu comigo por toda a graduação e continua hoje, os incentivos, a sinceridade, o companheirismo e os puxões de orelha. É muito bom saber que posso contar com vocês.

A minha orientadora, Vanessa Schramm, o aceite da orientação, a paciência e os conhecimentos compartilhados. Muito obrigado.

Aos seguintes professores do PPGA/UFCG, À Verônica Macário o incentivo à carreira acadêmica; À Suzanne Correia as incríveis aulas de administração e sociedade; A Edvan Aguiar os conhecimentos sobre métodos e técnicas de pesquisa. A Vinicius Moreira os ensinamentos no estágio de docência. À Fátima Martins os conhecimentos sobre sustentabilidade. À Petruska Machado os ensinamentos sobre técnicas de pesquisa. A Fernando Schramm o apoio na construção deste trabalho. Meus sinceros agradecimentos.

À banca examinadora, Kettrin Farias e Carmen Belderrain, as contribuições feitas a este trabalho.

Por fim, #partiudoutorado.

GOMES JÚNIOR, Alexandre de Araújo. **A FACILITATION MODEL BASED ON SOFT SYSTEMS METHODOLOGY TO SUPPORT DECISION MAKING IN BRAZILIAN WATERSHED COMMITTEES.** 128 pages. Master Thesis in Management –Federal University of Campina Grande, Paraíba, 2021.

ABSTRACT

This study aimed to propose a facilitation model based on Soft Systems Methodology to support decision-making processes that occur in Brazilian watershed committees. For this, three scientific papers were developed. The first paper presents a literature review, whose objective was to analyze the relevant empirical and theoretical literature about PSMs published over the last decade (2010-2020). In the second paper, we present a literature review, whose objective was to investigate the use of Problem Structuring Methods in Social-Ecological Systems. In these two papers both qualitative and quantitative Content Analysis was used to analyze the data. Thus, with the subsidies provided by these two reviews, the third paper was developed, in which a facilitation model based on Soft Systems Methodology for supporting decision-making processes in Brazilian watershed committees was proposed. Additionally, the facilitation model was used to structure an environmental conflict in Paraíba, Brazil. The model has the potential to be applied as a formal tool for supporting participatory decision-making in Brazilian watershed committees. Therefore, it is considered that this thesis brought contributions both to academic research and to society, as the evolution of the field of PSMs was presented, the way these approaches were applied in Social-Ecological Systems, the way these approaches were applied in Social-Ecological Systems, and the proposed model that can improve decision-making processes on water resources in Brazil.

Keywords: Problem Structuring Methods. Soft Systems Methodology. Complex Problems. Facilitation Model. Watershed committees.

GOMES JÚNIOR, Alexandre de Araújo. **A FACILITATION MODEL BASED ON SOFT SYSTEMS METHODOLOGY TO SUPPORT DECISION MAKING IN BRAZILIAN WATERSHED COMMITTEES.** 128 páginas. Dissertação de Mestrado em Administração - Universidade Federal de Campina Grande, Paraíba, 2021.

RESUMO

Este estudo teve como objetivo propor um modelo de facilitação baseado na *Soft Systems Methodology* para apoiar os processos de tomada de decisão que ocorrem nos comitês de bacias hidrográficas brasileiros. Para tanto, desenvolveram-se três artigos científicos. O primeiro artigo apresenta uma revisão de literatura, cujo objetivo foi analisar a literatura empírica e teórica relevante sobre Métodos de Estruturação de Problemas publicada na última década (2010-2020). No segundo artigo, apresentou-se uma revisão de literatura, cujo objetivo foi investigar a utilização de Métodos de Estruturação de Problemas em Sistemas Socioecológicos. Nestes dois artigos, utilizou-se Análise de Conteúdo qualitativa e quantitativa como técnica de análise de dados. Assim, com os subsídios proporcionados por essas duas revisões, desenvolveu-se o terceiro artigo, no qual foi proposto um modelo de facilitação baseado na *Soft Systems Methodology* para apoiar processos de tomada de decisão nos comitês de bacias hidrográficas brasileiros. Além disso, utilizou-se o modelo de facilitação para estruturar um conflito ambiental na Paraíba, Brasil. O modelo proposto tem potencial para ser aplicado como ferramenta formal de apoio à tomada de decisão participativa nos comitês de bacias hidrográficas brasileiros. Portanto, considera-se que esta dissertação trouxe contribuições tanto para a pesquisa acadêmica quanto para a sociedade, na medida em que se apresentaram a evolução do campo dos Métodos de Estruturação de Problemas, a forma como essas abordagens foram aplicadas em Sistemas Socioecológicos, e o modelo de facilitação que pode melhorar os processos de tomada de decisão sobre os recursos hídricos no Brasil.

Palavras-chave: Métodos de Estruturação de Problemas. *Soft Systems Methodology*. Problemas complexos. Modelo de Facilitação. Comitês de Bacias Hidrográficas.

LIST OF FIGURES

CHAPTER 2

CHAPTER 3

CHAPTER 4

LIST OF TABLES

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

LIST OF ABBREVIATIONS AND ACRONYMS

ANA	Brazilian National Water Agency
DCNOS	Brazilian National Department of Works against Drought
DPSIR	Drivers, Pressures, State, Impact and Response
OR	Operational Research
PSM	Problem Structuring Methods
SCA	Strategic Choice Approach
SES	Social-Ecological Systems
SIP	Sumé Irrigated Perimeter
SODA	Strategic Options Development and Analysis
SSM	Soft Systems Methodology
VSM	Viable System Model
WASAN	Waste and Source-matter Analyses
WoS	Web of Science

CONTENTS

CHAPTER 1
INTRODUCTION

1 Introduction

Systems Thinking was established as an essential paradigm to deal with the complexity of the real world as opposed to reductionist thinking, which proposes that to understand the world the difficulties must be divided into as many parts as possible (Cunha & Morais, 2016). Its origins are not precise, but some consider that the foundations of Systems Thinking reach back to ancient Western and Eastern philosophers, as Aristotle and Lao Tsu (Cabrera et al., 2008). Holism is an essential assumption of Systems Thinking, this means that the world is observed in terms of "wholes" that exhibits emergent properties, the opposite of reductionist thinking (Jackson, 2001).

This paradigm is often understood as an aggregation of ideas from numerous intellectual traditions (Cabrera et al., 2008). Until the 1970s, Systems Thinking paradigm was dominated by functionalism and positivism, therefore, from this perspective, it is understood that all systems could be identified by empirical observation and analyzed by the same methods as the natural sciences (Jackson, 2001). However, analyzing social systems or attempt to modify them is not a matter of trying to discover "laws" that govern those systems, as natural scientists do when analyzing nature's unchanging phenomena, because humans can act deliberately either confirm or refute any "laws" of social systems (Checkland, 1985). Therefore, these systems cannot be manipulated the better to achieve their aims, as proposed by functionalist and positivist Systems Thinking (Jackson, 2001).

Consequently, this traditional perspective of Systems Thinking came to be criticized, for example, for not being able to deal with complexity, and with the social and human aspects of problematic situations, that is, it was proving unable of dealing with unstructured and strategic problems (Jackson, 2001). These criticisms also resonated in Operational Research (OR). The discipline that emerged in the United Kingdom during the second world war, as the utilization of the scientific method to military operations (Hansen, 1989), also started to be widely used in public and private civil organizations (Kirby, 2007). However, after 30 years of success, the "golden age" of OR driven by global economic growth is over (Kirby, 2007). A crisis in OR was born that went through dissatisfaction with OR's methodology and practice (Hansen, 1989).

Discussions about the limitations imposed by traditional methods and models of OR, which are restricted to well-structured problems, that is, problems that can be expressed in terms of performance measures, constraints, and cause and consequence relationships, to the practice

of the discipline have emerged (Mingers & Rosenhead, 2004; Rosenhead, 1996, 2006). For Ackoff (1979), OR's traditional methods and models were no longer sensitive to the evolution of management needs because they could not deal with what he called "messy"- problematic situations that formed by complex systems of changing problems that interact with each other. Rittel calls these problematic situations of "wicked problems" as opposed to "tame problems", and states that the OR's traditional methods and modes only become "operational" when strategic decisions have already been made (Rittel & Webber, 1973).

According to Rosenhead (2006) these problematic situations are characterized by multiple actors, with differing perspectives and partially conflicting interests, significant intangibles, and perplexing uncertainties. Mingers (2011, p.731) add "a lack of reliable data, disagreement about the nature of the 'problem' and yet the need for agreement and commitment from stakeholders". Thus, as OR's traditional methods and models cannot deal with this type of situation, a new class of methods, named Problem Structuring Methods (PSMs), emerged. Therefore, PSMs gave rise to a new branch in the Operational Research field, which became known as "Soft Operational Research" (Ackermann, 2012; Mingers, 2011), in opposite to the term "Hard Operational Research" that is applied to the traditional methods and models. Indeed, PSMs are a response to the limitations of the traditional paradigm of Systems Thinking in the field of OR.

PSMs are a class of qualitative approaches of a participatory and interactive character, whose objective is to assist in the structuring of complex problems (Rosenhead, 1996). These approaches seek to address situations that happen routinely in social systems, as such companies, governments, and even in families. Complexity, arising from the need to understand a wide range of issues where there is no consensus, is a common feature of these situations (Rosenhead, 2006). According to Ackermann, (2012), PSMs are very focused on the need to meet the political and analytical demands of group decisions making.

The main PSMs are Soft Systems Methodology (SSM) (Checkland, 2001), Strategic Choice Approach (SCA) (Friend, 2001), and Strategic Options Development and Analysis (SODA) (Ackermann & Eden, 2001; Eden & Ackermann, 2001). However, there is a variety of PSMs: Hypergame Analysis; Interactive Planning; Metagame Analysis; Robustness Analysis; Strategic Assumption Surfacing and Testing (Rosenhead, 2006); Viable System Model (VSM) (Beer, 1984), Drivers, Pressures, State, Impact and Response (DPSIR) (Bell, 2012), and Waste and Source-matter Analyses (WASAN) (Shaw & Blundell, 2010).

These approaches have been applied in diverse areas business management (Abuabara et al., 2018; Damenu & Beaumont, 2017; J. Davis et al., 2010; Hanafizadeh & Ghamkhari, 2019; Savage et al., 2019);environmental management (Hart & Paucar-Caceres, 2014; Potts et al., 2015; Santos et al., 2019; Schramm & Schramm, 2018; Watkin et al., 2012); healthcare sector (Cardoso-Grilo et al., 2019; Carter et al., 2019; Heyrani et al., 2012; Sinclair et al., 2014; Vandenbroeck et al., 2014); social issues (Brocklesby & Beall, 2018; Capolongo et al., 2019; Laouris & Michaelides, 2018; Rodríguez-Ulloa et al., 2011); among others (Armstrong, 2019; Bell et al., 2017; Cloutier et al., 2015; Cronin et al., 2014; Eigbe et al., 2010).

Indeed, regardless of application area, SSM is the most frequently applied PSM. It was developed by Peter Checkland based on the notion that the complexity of the world cannot be understood as systems that can be modeled and optimized (Rosenhead & Mingers, 2001). Therefore, this methodology is a learning system about problematic situations, which aims to find accommodations and take actions to improve these situations (Checkland, 2001). SSM assumes that different actors make different evaluations about the real-world (ever-changing interacting flux of events and ideas) and systems logic is helpful to lead with real-world situations, which are usually complex (Checkland, 2001).

Thus, based on its features and evidence in the literature (Alexander et al., 2015; Hart & Paucar-Caceres, 2014; Hosseini & Rezaei, 2013; López et al., 2019; T. T. N. Nguyen et al., 2019; Potts et al., 2015; Sani et al., 2019; Suriya & Mudgal, 2013; Unalan, 2013; Watkin et al., 2012), SSM has a great potential to be used for supporting decision making about complex situations in Social-Ecological Systems, which are integrated systems of people and nature (Cumming, 2014), such as those that occur in Brazilian watershed committees- permanent deliberative, advisory, and propositional bodies responsible for operationalizing the decentralized water resources management provided in the Brazilian legal framework.

Therefore, the research question of this study is **“How can Soft Systems Methodology be used to support decision-making processes that occur in Brazilian watershed committees?”**

1.1 Objectives

1.1.1 Main objective

To propose a facilitation model based on Soft Systems Methodology to support decision-making processes that occur in Brazilian watershed committees.

1.1.2 Specific objectives

(i) To analyze the relevant empirical and theoretical literature about PSMs published over the last decade (2010-2020).

(ii) To investigate the use of PSMs in Social-Ecological Systems.

(iii) To propose a facilitation model based on SSM for supporting decision-making processes in Brazilian watershed committees.

1.2 Motivation

In Brazil, Federal Law Nº. 9.433/97 institutes the National Water Resources Policy and creates the National Water Resources Management System, that is, it regulates water resources management in the country. This legal framework provides that the management of these resources must be decentralized and participative. Thus, watersheds are managed by committees, which are permanent deliberative, advisory, and propositional bodies composed of representatives of different segments of the society (public authorities, water users, and representatives of civil society).

Among the responsibilities of these committees are to promote debates on issues related to water resources, to arbitrate conflicts related to water resources, to approve and monitor the execution of a management plan for the watershed, to establish mechanisms for charging water resources, and to determine criteria and promote the apportionment of construction cost in the watershed (Brasil, 1997). Therefore, as the decision-making process on these issues is participatory and involves multiple actors, it can be very complex (Silva et al., 2010), and finding consensus can be very difficult because multiple actors with different points of view, values, perceptions, and conflicting interests are involved (Schramm & Schramm, 2018). Thus, a formal approach for supporting participatory decision-making processes that occur in Brazilian watershed committees is necessary and urgent

1.3 Research method

This thesis used the model of scientific articles as foreseen in the regulation of the Programa de Pós-Graduação em Administração da Universidade Federal de Campina Grande (PPGA/UFCG). To achieve the main objective, the research was divided into two phases:

exploratory and descriptive, and qualitative and quantitative procedures were used. In the exploratory phase, two papers were developed, which allowed us to analyze how research on PSMs have been developed in the last decade, and how these methods are used in Social-ecological Systems. These two papers gave us the basis to propose the facilitation model based on SSM (3rd paper), which is the descriptive phase of the research. Table 1 summarizes the research design.

Table 1: Research design. Source: author, based on Mazzon, (1981)

Research problem: How can Soft Systems Methodology be used to support decision-making processes in Brazilian watershed committees?			
Main objective: To propose a facilitation model based on Soft Systems Methodology to support decision-making processes in Brazilian watershed committees.			
Specific objectives	**Data source**	**Data analysis**	**Paper**
To analyze the relevant empirical and theoretical literature about PSMs published over the last decade (2010-2020).	Bibliographic: Web of Science ™ Core Collection (WoS).	Qualitative and quantitative: content analysis	Problem Structuring Methods: a review of advances over the last decade.
To investigate the use of PSMs in Social-Ecological Systems.	Bibliographic: Web of Science ™ Core Collection (WoS).	Qualitative and quantitative: content analysis	Problem Structuring Methods in Social-Ecological Systems.
To propose a facilitation model based on SSM for supporting decision-making processes in Brazilian watershed committees.	Bibliographic: Articles 1 and 2, Soft Systems Methodology foundations, and previous study about an environmental conflict	Qualitative: Soft Systems Methodology	Facilitation Model Based on SSM for Supporting Brazilian Watershed Committees;

The 1st paper presents a literature review whose main objective was to analyze the relevant empirical and theoretical literature PSMs published over the last decade (2010-2020). To achieve this, a search in the Web of Science™ Core Collection (WoS) was done to collect the data, which were analyzed through both quantitative and qualitative Content Analysis. Thereby, it was possible to analyze the development of research on PSMs in the last decade by presenting the growth in the number of publications, where these researches were developed, the authors with the highest number of publications, and which journals publish more on the theme. In addition, the areas in which PSMs are applied, and the most frequently used PSM were presented. Furthermore, theoretical, and methodological advances in this field were discussed, in addition to emerging topics.

The 2nd paper provides a literature review article whose objective was to investigate the use of Problem Structuring Methods in Social-Ecological Systems, focusing on three

dimensions of analysis: (i) overview, which includes geographical location, type of PSM used, and application context; (ii) characteristics of the models, which includes the approaches used for collecting input data, types of participants, inputs, and outputs of the models; and (iii) the results dimension, which includes the main benefits and limitations of the models. To achieve this, both quantitative and qualitative Content Analysis was performed through an iterative process comprised of four steps: material collection, descriptive analysis, category selection, and material evaluation. The data source was Web of Science™ Core Collection (WoS).

Indeed, these first two papers provided the necessary subsidies for choosing the PSM to be used in the proposed facilitation model (SSM) and to guide how this model could be developed. Thus, in the 3rd paper, a facilitation model based on SSM for supporting decision-making processes in Brazilian watershed committees was proposed. To achieve it, SSM foundations combined with the characteristics of these committees were used. The facilitation model is composed of phases, steps, instructions, and theoretical and graphic elements to formalize participatory and democratic decision-making in these bodies. Additionally, the facilitation model was used to structure an environmental conflict that exists in an area of the watershed of the Paraiba do Norte River.

1.4 Thesis structure

This thesis is organized into five chapters, including this introduction, which contains the theoretical context, objectives, motivation, and research method used in the study. Chapter 2 presents the 1st paper - Problem Structuring Methods: a review of advances over the last decade. Chapter 3 shows the 2nd paper - Problem Structuring Methods in Social-Ecological Systems. Chapter 4 presents the 3rd paper - Facilitation Model Based on Soft Systems Methodology for Supporting Brazilian Watershed Committees. Finally, the final remarks are presented in Chapter 5, with the main results and contributions, limitations of this research, and recommendations for future works.

The three papers followed the rules of the respective journals to which they were submitted, and the list of references cited is at the end of this document.

CHAPTER 2

FIRST PAPER

Problem Structuring Methods: a review of advances over the last decade.

Problem Structuring Methods: A Review of Advances Over the Last Decade[1]

Abstract

The Problem Structuring Methods (PSMs) are a set of interactive and participatory modeling approaches for dealing with unstructured complex problems, which are characterized by the existence of multiple actors, with differing perspectives and conflicting interests, trying to identify alternatives for solving a problematic situation in an environment with uncertainties. In this paper, we provide a literature review about PSMs over the last decade (2010-2020), focusing on verifying the distribution of papers according to year, journals, countries, and authors; to identify the most frequent PSMs and areas of application; and to present methodological and theoretical advances, and emerging topics. The content analysis technique was used to analyze the papers. From 2015 on there was a significant increase in the number of studies that address the PSMs and the years 2018 and 2019 concentrate around one-third of the number of papers. Most of the papers present applications of PSM in different areas that were classified into five categories: business management; environmental management; healthcare sector; social issues; and other areas. Regardless of the application area, the Soft System Methodology (SSM) is the most frequently used PSM and a discussion is provoked about this finding. The paper also presents the theoretical and methodological advances and emerging topics in this discipline.

Keywords: Problem structuring methods. Soft Systems Methodology. Strategic Choice Approach. Strategic Options Development and Analysis. Soft OR. Literature review.

1 Introduction

Operational Research (OR) is a discipline that encompasses the development and/or application of analytical methods aiming to provide improved decision making in different contexts; traditionally, these methods are addressed to solve well-structured problems, that is, problems that can be expressed in terms of mathematical expressions (Mingers & Rosenhead, 2004; Rosenhead, 1996, 2006); the so called "Hard OR" search optimization and objectivity (Ackoff, 1979). However, in various situations the nature of decisions is complex, making it difficult, or even impossible, to model the problems mathematically. According to Ackoff, (1979), traditional OR's methods and models are not meant for dealing with complex situations, which the author called "messy problems" and Rittel & Webber, (1973) called "wicked problems". Complex situations are problems that involve multiple actors, with differing perspectives and partially conflicting interests, significant intangibles, and perplexing uncertainties (Rosenhead, 2006). These situations, despite being extremely common, are strategic, not short-term, and narrowly focused (Mingers, 2011).

[1] Authorship: Alexandre de Araújo Gomes Júnior & Vanessa Batista Schramm, submitted to Systemic Practice and Action Research (SPAA) (Qualis CAPES: A1) on June 21, 2020.

Since the late 1960s, specialists started debates about claims for objectivity of hard OR models and the limitations imposed on OR practice by its concentration in well-structured problems (Rosenhead, 1996). This movement for a reevaluation of OR and their customer base was started in the OR community in Britain followed by some American researchers, such as Russell Lincoln Ackoff, Charles West Churchman, and Hugh Jordan Miser (Kirby, 2007). In his criticism, Ackoff (1979) pointed out that Hard OR were no longer sensitive to the evolution of management needs. In this context, a new class of methods, named Problem Structuring Methods (PSMs), emerged, giving rise to a new branch in the OR, which became known as "Soft OR" (Ackermann 2012; Mingers 2011). As pointed out by Mingers (2011), despite having existed for more than 50 years, efforts are still necessary to recognize the Soft OR as a legitimate Operational Research discipline.

PSMs are a set of interactive and participatory modeling approaches that help groups of diverse actors to alleviate a common complex and problematic situation (Mingers & Rosenhead, 2004; Mingers & White, 2010). These methods offer a well-defined and an agreed upon structure, originating from differing perceptions of the situation, for this type of circumstances can help generate a consensus or to facilitate negotiations, that is, these methods help structuring the problem instead of solving them directly (Rosenhead, 1996). Therefore, PSMs manage the complexity of these messy situations aiming actors to develop a comprehensive appreciation of the situation and thereby they are able to achieve a common understanding about it (Ackermann, 2012).

Smith & Shaw (2019) point out some characteristics of PSMs: they build models that are qualitative; they facilitate engagement and improve the participants' learning about the problem; they seek to create a holistic understanding of the system, and their inputs are the participants' subjective understandings of the world. Other characteristics of PSMs are: the credibility of the model is established by preserving the contribution of the participants; the rationality of the procedures aim to promote confidence; knowledge is structured through various stages of analysis; and there are distinct phases for convergent and divergent thoughts (Schramm & Schramm, 2018), which help the group involved in the complex problem to negotiate a set of improvements and actions to resolve the situation (Ackermann, 2012).

In a retrospective and prospective study about PSMs, Rosenhead (2006) presents some areas in which these methods can be useful: development planning, community operational research, large group interventions, information systems projects, and management of risks.

Thirteen years after Rosenhead's study, (Harwood, 2019b) points out areas in which research using PSMs can be fruitful: strategy development; change management; sustainable development; social enterprise; and teaching research methods. In the last decade, PSMs have been applied in diverse areas: business management (Abuabara et al., 2018; Damenu & Beaumont, 2017; J. Davis et al., 2010; Hanafizadeh & Ghamkhari, 2019; Savage et al., 2019);environmental management (Hart & Paucar-Caceres, 2014; Potts et al., 2015; Santos et al., 2019; Schramm & Schramm, 2018; Watkin et al., 2012); healthcare sector (Cardoso-Grilo et al., 2019; Carter et al., 2019; Heyrani et al., 2012; Sinclair et al., 2014; Vandenbroeck et al., 2014);social issues (Brocklesby & Beall, 2018; Capolongo et al., 2019; Laouris & Michaelides, 2018; Rodríguez-Ulloa et al., 2011); among others (Armstrong, 2019; Bell et al., 2017; Cloutier et al., 2015; Cronin et al., 2014; Eigbe et al., 2010).

The foremost PSMs are Soft Systems Methodology (SSM) (Checkland, 2001), Strategic Choice Approach (SCA) (Friend, 2001), and Strategic Options Development and Analysis (SODA) (Ackermann & Eden, 2010; Eden & Ackermann, 2001). SSM is a learning system that consists of the construction of a graphical description of a complex situation, construction of a conceptual model based on the perspective and interests of decision makers, comparison of both real and conceptual models, identification of changes that are culturally feasible and systemically desirable and take action to improve the complex situation. SODA uses cognitive mapping to represent the perceptions of individuals about the situation, creating a holistic and common understating about the complex situation and helping the group to achieve an agreement on how to solve it. SCA helps actors working together to make decisions by focusing their attention on possible modes of managing uncertainty; it is formed by a process with four complementary modes: shaping, in which decision-makers address the problems; designing, whose focus is formulating feasible actions to improve the problem; comparing, for comparing these actions with each other; and choosing, which is the stage to achieve an agreement in relation to the action the group will chose. Other PSMs that are cited by Rosenhead, (2006) are: Hypergame Analysis; Interactive Planning; Metagame Analysis; Robustness Analysis; Strategic Assumption Surfacing and Testing. Other methods that are described in the literature as PSMs are: Viable System Model (VSM) (Beer, 1984), Drivers, Pressures, State, Impact and Response (DPSIR) (Bell, 2012), and Waste and Source-matter Analyses (WASAN) (Shaw & Blundell, 2010).

In the past ten years, some literature reviews about PSMs and related topics were published in specialized literature. Mingers & White (2010) reviewed the contribution of

Systems Thinking to Operational Research in the first decade of the 2000s. Franco & Montibeller (2010) discussed the facilitated modeling as an intervention tool and offered a formal definition for it. Paucar-Caceres (2010) performed a review of papers to verify paradigmatic changes in Management Science; the review was limited to papers that were published in OMEGA, International Journal of Management Science, from 1973 to 2008. Mingers (2011) provided a discussion about the recognition of Soft Operational Research as a legitimate Operational Research discipline. Howick & Ackermann (2011) reviewed the mixing of methods in Operational Research. Paucar-Caceres (2011) explored the differences between trends in Operational Research, a research developed in England and the United States. Khadka et al. (2013) performed a literature review of PSM use in participatory forest planning. A. P. Davis et al. (2015) reviewed Systems Thinking's application to organizational performance in higher education and healthcare. Ranyard et al. (2015) discussed the influences of Business Analytics and PSM in the future of Operational Research.

More recently, Patrício et al. (2016) reviewed the use of DPSIR in ecosystem management. Marttunen et al. (2017) reviewed the combination of Multi-Criteria Decision Analysis and PSMs. Powell & Mustafee (2017) presented a study about the use of SSM in the health care sector. Renzi & Leali (2017) reviewed decision-based design methods in engineering design contexts. Hanafizadeh & Mehrabioun (2018) reviewed the use of SSM in papers that were published between 2000 and 2015. Scott et al. (2016b) reviewed the literature about Group Model Building. From a literature review, Smith & Shaw (2019) provided a framework to determine which approaches can be considered PSMs. Warren et al., (2019) provided a bibliometric meta-analysis of the use of SSM. Wright et al. (2019) performed a review about the use of scenarios from the Intuitive Logics School to address wicked problems.

The motivation for this work stems from the need to analyze the relevant empirical and theoretical literature about PSMs. In this paper, a literature review about PSMs is provided, focusing on verifying the distribution of papers according to year, journals, countries, and authors; to identify the most frequent PSMs and areas of application; and to present methodological and theoretical advances, and emerging topics. The reviewed database is comprised of 322 papers that were published in peer-reviewed journals over the last decade (2010-2020). This paper is organized as follows: Section 2 presents the methodology used in this study; Section 3 presents the descriptive and bibliometric analysis; Section 4 presents applications as well as methodological and theoretical advances; Section 5 shows the discussion, and the conclusion is presented in Section 6.

2 Research Methodology

Literature reviews aim to describe, summarize, evaluate, clarify, and/or integrate the literature from a research field without collecting or analyzing any primary data (Cooper, 1988; Paré et al., 2015). The reviewed papers may be empirical, theoretical, critical/analytic, or methodological in nature (Cooper, 1988; Flick, 2009). In this paper, a review of the relevant empirical and theoretical literature about PSMs that were published in peer-reviewed journals between 2010 and February 2020 is provided. To this, the process suggested by Creswell, (2010) was followed, which involved preparing, conducting different analyses, understanding, representing, and performing an interpretation of the data (Figure 1).

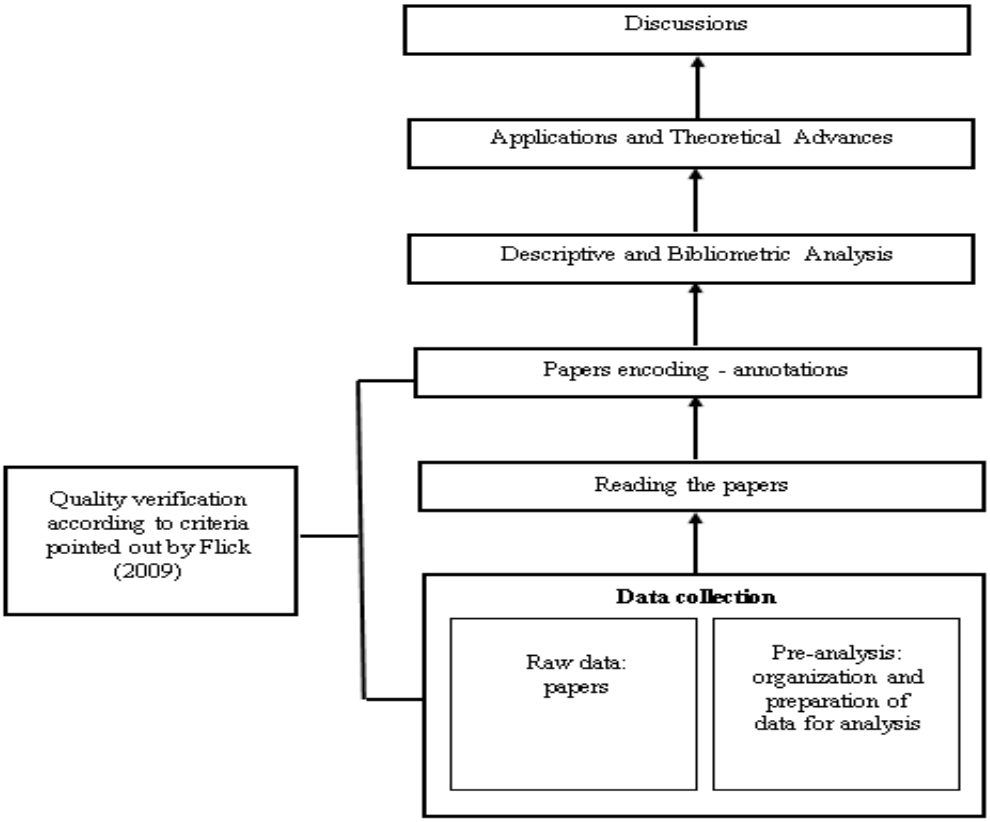

Figure 1: Research process (adapted from Creswell, (2010)

In order to verify the quality of the selected documents, the criteria informed by Flick (2009) were adopted: (i) authenticity that corresponds to the verification of the document's genuineness; (ii) credibility that refers to the search for errors and distortions in documents; (iii) representativeness that refers to the typicality of the document, that is, whether the documents found have the typical characteristics of documents of the type, in this case papers; and (iv) significance that refers to the clarity of the document. This verification was performed during

the first three phases of the research process: data collection, reading the papers; and papers encoding. Papers that do not meet these criteria were excluded from the database.

2.1 Data collection: delimitations and the search for literature

The data collection phase included the establishment of the limits for the study, the collection itself, and the protocol for recording information (Creswell, 2010). First, we chose the keywords for the research: "problem structuring method*" or "soft systems methodology" or "strategic choice approach" or "strategic options development and analysis". With this, it was assured that the returned papers refer to the main PSMs (that is SSM, SODA, and SCA) and papers that refer to other techniques that are PSMs or used as a PSM.

The database used was the Web of Science™ Core Collection (WoS) and the following indexes were considered: Science Citation Index Expanded (SCI-EXPANDED), Social Science Citation Index (SSCI), and Emerging Sources Citation Index (ESCI). This database was chosen because it is the most reputable and comprehensive in the most diverse areas of knowledge (Bhardwaj, 2016), with over 1.7 billion references cited from more than 159 million records (Clarivate, 2020). The search was performed by topic, the keywords were searched in the following fields of the paper: title, abstract, authors' keywords, and keywords plus. English publications were searched between 2010 and 2020 in peer-reviewed journals. Table 1 shows the parameters of the search, which was performed in February 2020.

Table 1: Web of Science™ search parameters

Database	Web of Science™ core colletion
Indexes	*Science Citation Index Expanded (SCI-EXPANDED); Social Sciences Citation Index (SSCI); e Emerging Sources Citation Index (ESCI).*
Search type	Basic search
Field Labels	Topic
Keywords	"problem structuring method*" or "soft systems methodology" or "strategic choice approach" or "strategic options development and analysis"
Document Type	*"Article" or "review".*
Period	2010-2020
Languages	English

Firstly, the database search returned 347 documents. Then, the criteria document type and language were applied, resulting in 332 papers. These documents were submitted to a preliminary analysis, taking into account the criteria pointed out by Flick, (2009). After that, ten papers were excluded, and 322 papers were submitted for analysis.

2.2 Data analysis

The data analysis technique adopted in this study was the Content Analysis. This technique is mainly used to analyze textual data and it comprises two aspects: mechanical and interpretive. The first aspect involves organizing and subdividing the data. The second aspect involves the conceptual process of determining what categories are meaningful (Brewerton & Millward, 2001), that is, extracting meaning from the data (Creswell, 2010).

Both quantitative and qualitative content analysis was conducted. The first analysis type was used to generate numerical values, such as frequencies, presentations, or indexes, from the collected data, while the second emphasizes the meaning of that data (Brewerton & Millward, 2001).

The analysis was separated into three parts: (i) descriptive analysis; (ii) bibliometric analysis; and (iii) qualitative analysis. In the descriptive analysis, the distribution of reviewed papers according to publication year, journals, countries, authors was verified, as well as the research methodologies applied in the papers. In the qualitative analysis, the papers were analyzed in terms of which areas they were applied, the most used PSMs, and we presented the methodological and theoretical developments.

In the bibliometric analysis, both the keyword co-occurrence network and the co-citation of authors network were created, using the VosViewer version 1.6.14 tool (N. Van Eck & Waltman, 2010). The keyword co-occurrence network is a set of interconnected keywords used in the papers, in which the frequency of occurrence of these words and the relationship between them are represented (N. J. Van Eck & Waltman, 2017). The co-citation network shows the frequency in which two papers are cited together by other papers; the closer authors are in the graph, the more co-citations their papers received.

Moreover, the Citation Network Explorer (CitNetExplorer) version 1.0.0 tool was applied to aggregate the publications, where each node represents a publication, based on a citation relationship. The vertical location of the paper was determined by the year of publication and the horizontal location was determined by the proximity of the citation relationship between the papers (N. Van Eck & Waltman, 2014).

3 Descriptive and Bibliometric Analysis

3.1 Distribution of papers according to year, journals, countries, and authors

In order to present the distribution of the papers per year, we removed the 5 papers that were published in 2020, to consider only completed years. Therefore, Figure 2 presents the distribution of 317 papers that were published from 2010 to 2019.

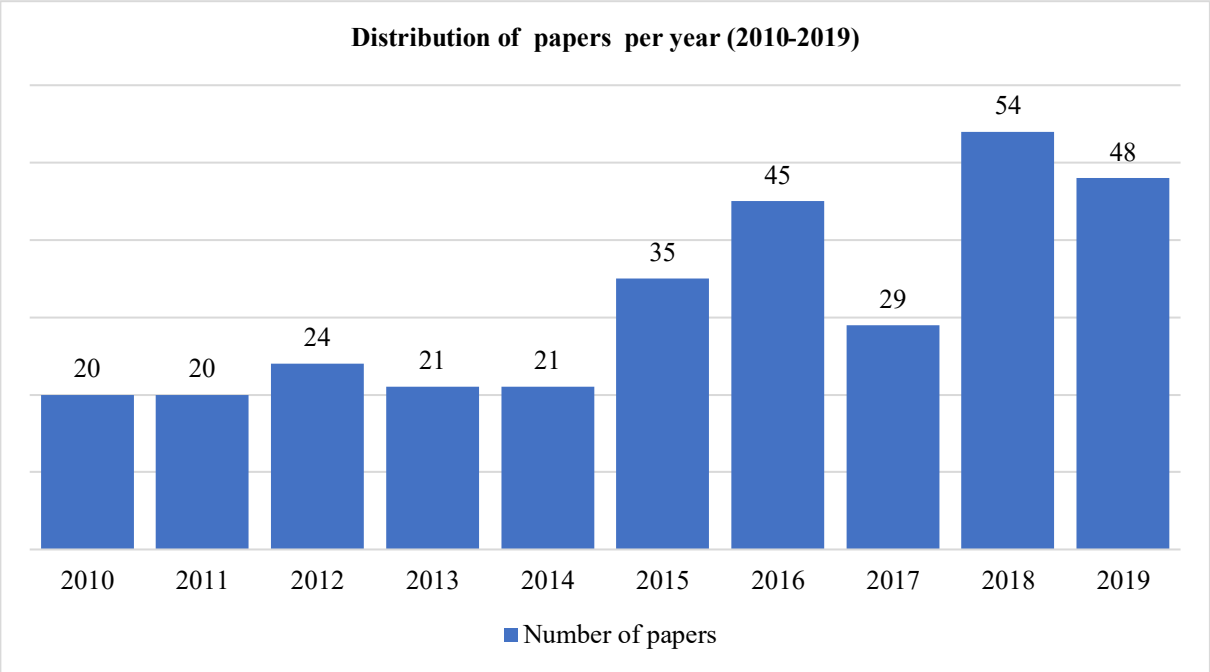

Figure 2: Distribution of papers per year (2010-2019*)*

In the first five years, ~20 papers were published per year. The graph shows an upward trend in number of publications from 2015 onwards, with ~32% having been published in 2018 and 2019. However, in 2017, the number of publications decreased significantly, perhaps because of the European Journal of Operational Research, which is the journal with highest number of publications related to PSMs in the period, it had published only one paper on this topic in that year. In 2018, this same journal published 16 papers related to PSMs, provoking an increase of 86% in the number of papers in relation to 2017.

The reviewed papers were published in 128 different journals, but five of them were responsible for 47% of the publications: European Journal of Operational Research (58 papers, ~18%); Journal of the Operational Research Society (31 papers, ~9.6%); Systemic Practice and Action Research (31 papers, ~9.6%); Systems Research and Behavioral Science (23 papers, ~7%); and Group Decision and Negotiation (9 papers, ~2,8%). Figure 3 shows the distribution of papers by journal.

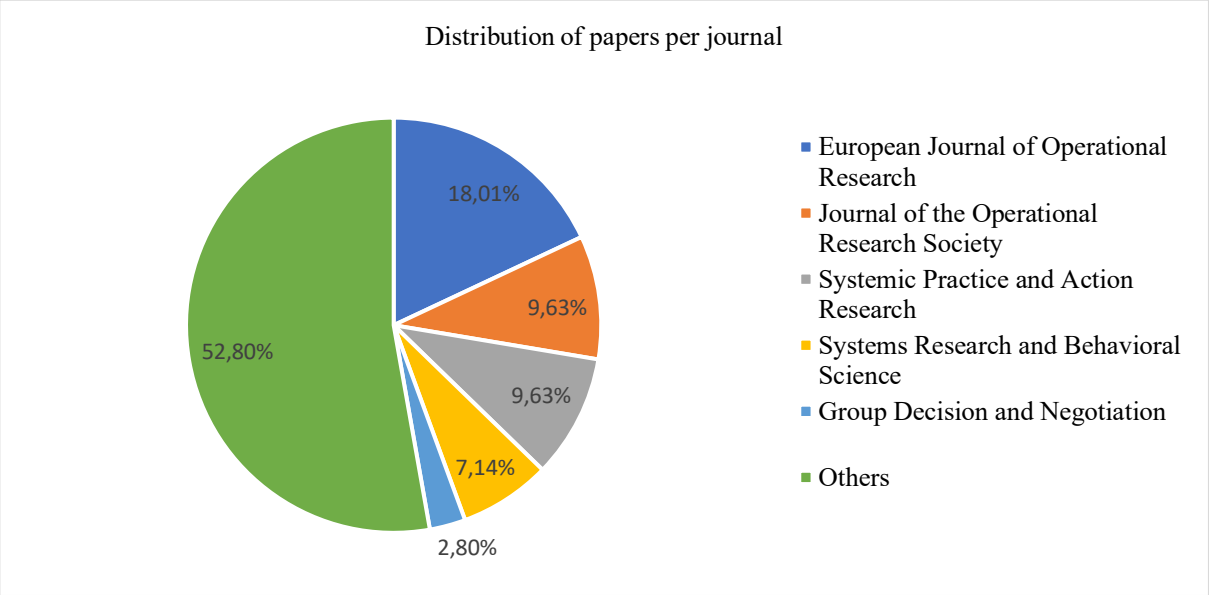

Figure 3: Distribution of papers per journal

Regarding the origin of the papers, they were produced by authors from 61 countries. England is the country of origin with the most papers: 117, followed by Australia with 41 publications, US with 37 publications, Italy with 21 publications, New Zealand with 20 publications and Brazil with 19 publications. The leadership of British publications can be explained by the high level of criticism and dissatisfaction with the traditional Operational Research paradigm in this country. Another important information that we can extract from the data is that, given the importance of the USA in the world, a small number of publications in this country may reveal some resistance of North American researchers to the Soft paradigm of Operational Research, in particular the PSMs, as observed in the studies of Paucar-Caceres, (2010, 2011). Regarding Brazil, most of papers (~89%) were published from 2015 onwards, which indicated that the interest about this topic by academics and practitioners in the country is recent and growing, being lead authors of 5.6% of publications; in a previous review carried out by Mingers, (2011), lead authors of the papers from Brazil were responsible for only 2% of publications on PSMs.

The total number of authors is 797 and the ten authors that have the highest number of publications are: Yearworth, M. (12 papers), White, L. (9), Paucar-Caceres, A. (9), Mingers, J.

(8), Franco, A. (7), Tavella, E. (7), Midgley, G. (7), Sauser, B. (6), Cavana, R (5), and Hanafizadeh, P (5). These 10 authors are responsible for ~23% of publications. We can say that they are PSM thinkers.

3.2 Research methodologies applied

Five research methodologies were differentiated (Figure 4): 212 papers (~ 66 %) are case studies; 49 papers (~ 15%) aim to develop the theoretical assumptions of PSMs; 25 papers (~8%) propose new approaches to structure problems, but without presenting its applications; 18 papers (~ 5.6%) are surveys that seek to investigate characteristics of PSM interventions.; 18 papers (~5.6 %) are literature review papers . It is important to note that we did not assess the methodological rigor of these papers.

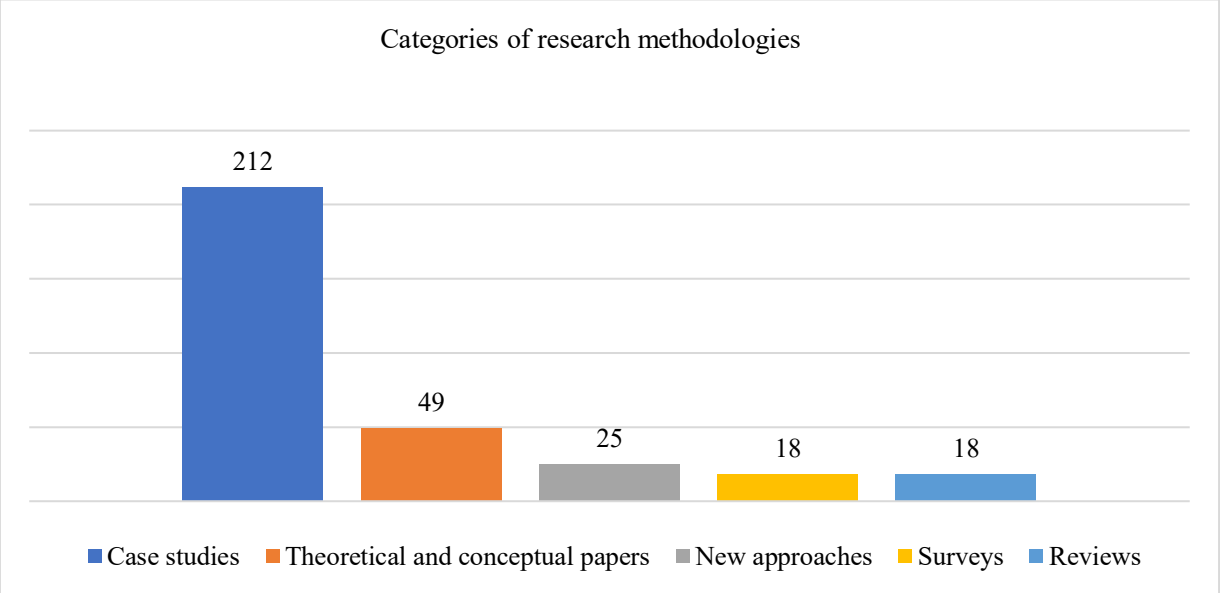

Figure 4: Categories of research methodologies

3.3 Analysis of keywords co-occurrence

The total keywords in papers is 997. To create a well-defined bibliographic map, we have defined that a minimum of five occurrences per keyword. In addition, synonyms were removed, resulting in 30 keywords that were aggregated into two clusters in the keywords co-occurrence network (Figure 5): soft system methodology (green) and problem structuring methods (red). In this map, the nodes represent the keywords - the larger the node the greater the relevance of the item is in the network; the length of the arcs represent the strength of the link between the keywords - the closer they are the stronger the link is.

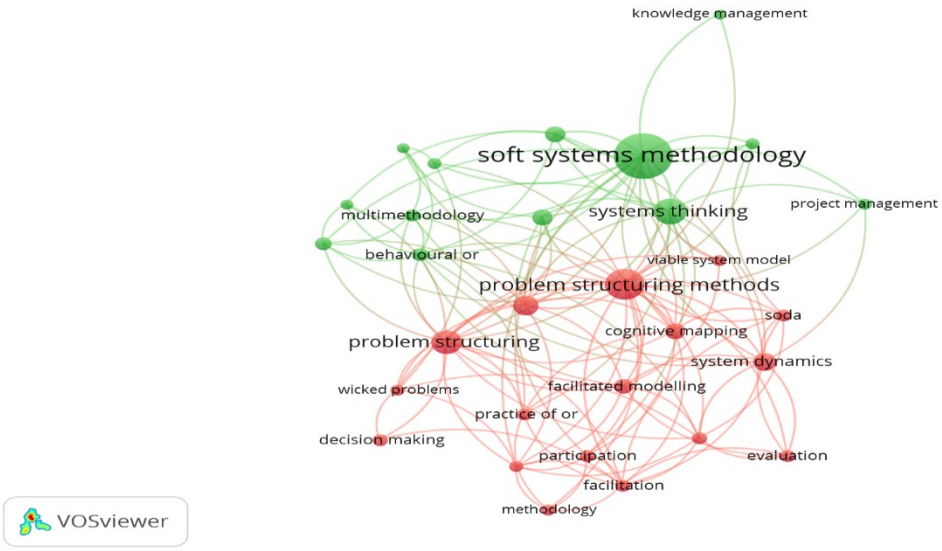

Figure 5: Keywords co-occurrence network

The green cluster contains 13 keywords: Soft Systems Methodology (93 occurrences), Systems Thinking (29 occurrences), Action Research (12 occurrences), Community Operational Research (12 occurrences), Strategic Choice Approach (8 occurrences), Behavioral Operation Research (8 occurrences), Multimethodology (7 occurrences), Boundary Critique (6 occurrences), Project Management (6 occurrences), Sustainability (6 occurrences), Critical Systems Thinking (5 occurrences), Decision Process (5 occurrences), and Knowledge Management (5 occurrences).

Analyzing this cluster, we observed that the SSM is the most frequently used and studied PSM. The theoretical and methodological bases of this method also appear in the clusters: Systems Thinking, Action Research, Boundary Critique, and Critical Systems Thinking. Moreover, we can conclude that SSM appears in emerging areas of Operational Research, as indicated by the presence of the keywords "Community Operational Research" and "Behavioral Operation Research". The presence of the keywords "Strategic Choice Approach" and "Multimethodology" indicates that SSM is being applied combined with other methods. In addition, the cluster shows the area in which SSM is being applied (Knowledge Management, and Project Management). Finally, we observed the presence of words that indicate the objectives of applying this method, which are support for the "Decision process" and the "Sustainability" of decisions.

The red cluster contains 17 keywords: Problem Structuring Methods (41 occurrences), Problem Structuring (26 occurrences), Soft Operational Research (17 occurrences), System Dynamics (14 occurrences), Cognitive Mapping (11 occurrences), Facilitated Modeling (10 occurrences), Decision Making (7 occurrences), Evaluation (7 occurrences), Facilitation (7 occurrences), Group Model Building (7 occurrences), Participation (7 occurrences), Practice of Operational Research (7 occurrences), SODA (7 occurrences), Methodology (6 occurrences), Simulation (6 occurrences), Viable System Model (6 occurrences), and Wicked Problems (6 occurrences). This cluster is broader, with the presence of several methods and techniques and the presence of keywords that refer to PSMs interventions, such as: Facilitated Modeling, Decision Making, Facilitation, Participation, and Practice of Operational Research.

3.4 Analysis of authors co-citations

Regarding the co-citation authors' network, 9952 authors were cited in the reviewed papers. To present a well-defined bibliographic map, we have defined a minimum number of 20 citations per author. Applying this criterion, a co-citation network was constructed with 68 authors who were distributed into four clusters (Figure 6): red, blue, green, and yellow. In this map, the nodes represent the authors in the reviewed papers - the larger the node the greater the relevance the item in the network is. The length of the arcs represents the strength of the link between the authors - the closer they are the stronger the link is.

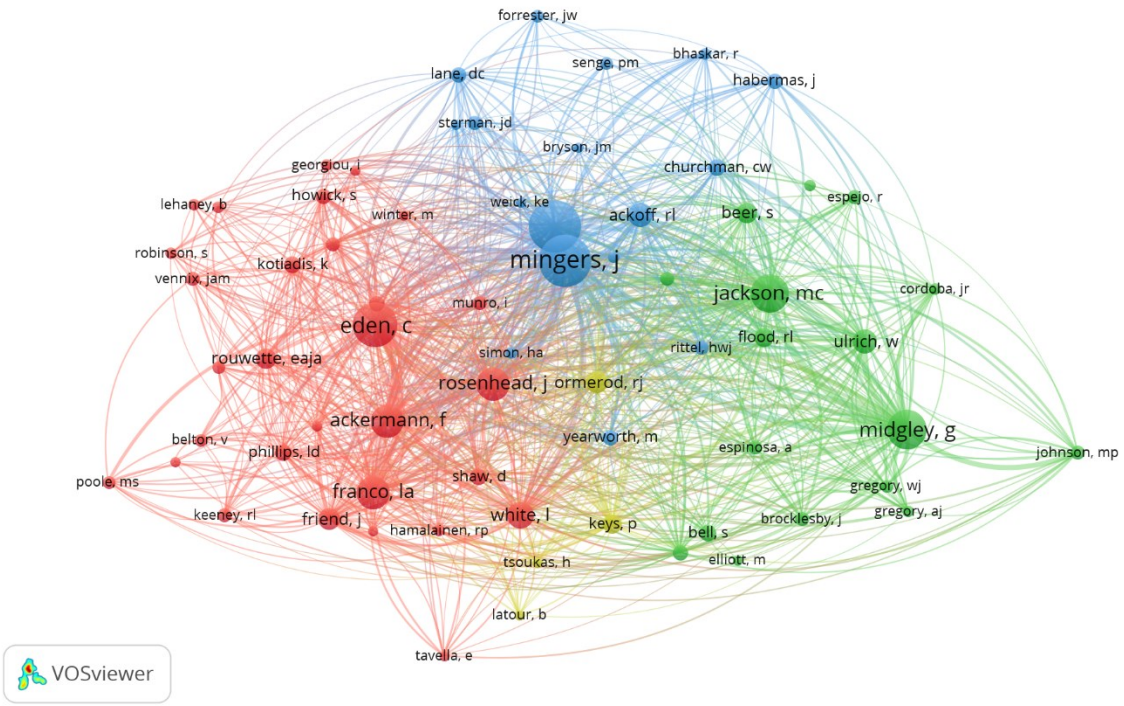

Figure 6: Co-citation of authors' network

The red cluster is the largest one with 30 authors: Eden, C. (350 citations), followed by Rosenhead, J. (204), Franco, L. A. (197), Ackermann, F. (191), and White, L. (136). The former is the creator of SODA and has a lot of work developed in collaboration with Ackermann, F., who also studies the benefits of PSMs. Rosenhead, J is an editor of books on PSMs, and Franco, L.A. works with aspects related to facilitated modeling.

The blue cluster is the second largest with 17 authors: Mingers, J. (489), followed by Checkland, P. (476), Ackoff, R. (106), Churchman, C. (52), and Lane, D. (42). This cluster contains the authors with the highest number of citations in the entire network: Mingers, J. and Checkland, P. The former is a book editor about PSMs, and the latter is the creator of the SSM, which according to our analysis is the most applied PSM. Ackoff, R. and Churchman, C. are System Thinking academics and were precursors of criticism directed at traditional methods of Operational Research. Lane, D. develops research on Systems Dynamics.

The green is the third cluster with 17 authors: Midgley G. (274), followed by Jackson, M. (256), Ulrich, W. (109), Beer, S. (81), and Flood, R. (72). The first author of this cluster develops research on Systemic Interventions. Jackson, M. develops research related to Critical Systems Thinking. Ulrich W. develops research on Critical Heuristics of Social Planning, which has served as the basis for Midgley's work about Systemic Interventions and Theory of Boundary Critique. Beer, S. studies the relationship between Cybernetics and Management. Flood, R. developed a methodology for choosing appropriate methods for interventions. Finally, the yellow, a secondary cluster, with four authors: Ormerod, R (82), Keys, P (66), Latour, B (20), Tsoukas, H. (20). The first author studies the use of PSMs in organizations and in Information Systems. Keys, P. studies the design of interventions, more specifically on the issue of expertise. Latour, B developed the Actor-Network-Theory. Tsoukas, H. studies topics related to Complex Thinking. This map of co-citations presents us with the theoretical basis of the methods used in the reviewed papers and the basis for structuring problems.

3.5 Analysis of the network of citations

The citation network analysis of 316 papers was performed using the CitNetExplorer Software. Six papers were not considered for this analysis because they are classified as "early access" in the Web of Science database, that is, documents that are still in process of publication, and the software does not process this type of document. To construct the network, a minimum number of five citation links per paper has been established as an exclusion criterion. With this, a network with 62 publications was constructed (Figure 7).

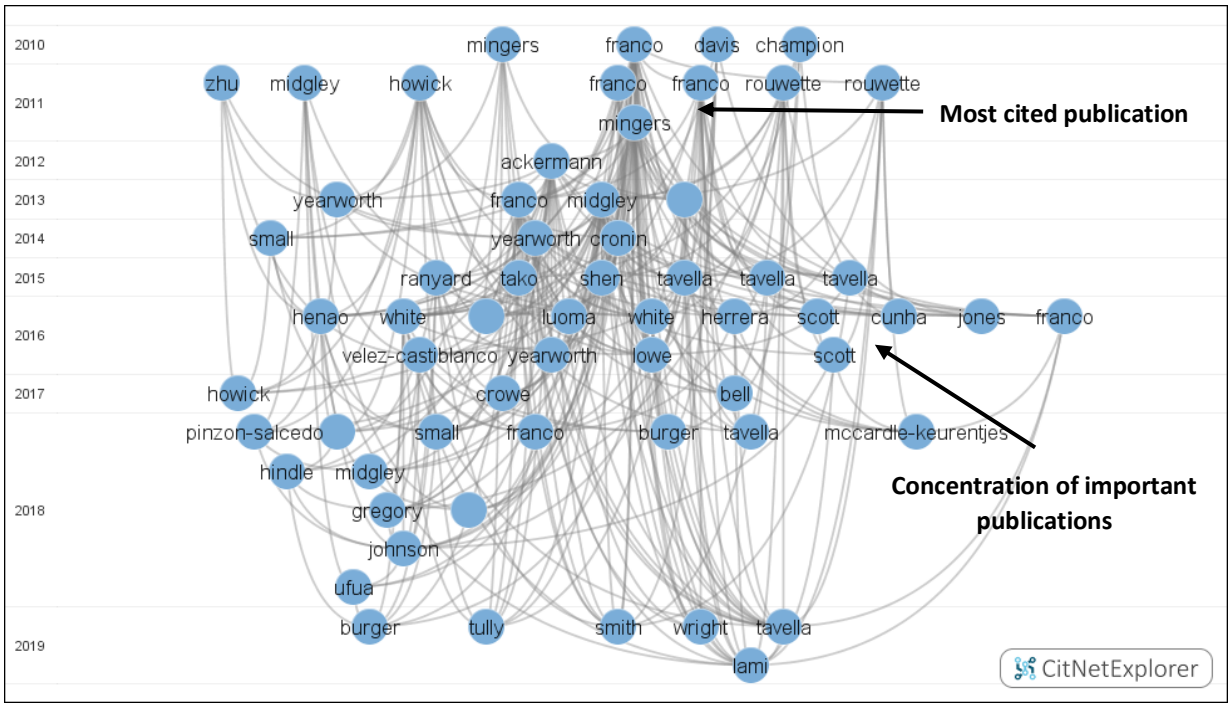

Figure 7: Main publications about PSM in the period from 2010 to 2020

Note that there is a concentration of these publications between the years 2015 and 2016. The ten most important publications and their respective citation score are summarized in Table 2.

Table 2: Ten most influential publications in the citation network

Nº	Paper Title	Cit. Score
1	Soft OR comes of age-but not everywhere! (Mingers, 2011)	43
2	Facilitated modelling in Operational Research (Franco & Montibeller, 2010)	42
3	Problem structuring methods 'in the Dock': Arguing the case for Soft OR (Ackermann, 2012)	42
4	Towards a new framework for evaluating systemic problem structuring methods (Midgley et al., 2013)	35

5	A review of the recent contribution of systems thinking to Operational Research and management science (Mingers & White, 2010)	31
6	Rethinking soft or interventions: Models as boundary objects (Franco, 2013)	20
7	Mixing or methods in practice: Past, present and future directions (Howick & Ackermann, 2011)	19
8	Understanding multi-methodology: Evaluating the perceived impact of mixing methods for group budgetary decisions (Franco & Lord, 2011)	17
9	Decision development in facilitated modelling workshops (Franco & Rouwette, 2011)	17
10	The non-codified use of problem structuring methods and the need for a generic constitutive definition (Yearworth & White, 2014)	15

The most important publication of the analyzed period is "Soft OR comes of age — but not everywhere!" from John Mingers, in which the author presents the main PSMs, argues about the success of PSMs both in theory and in practice, and comments on their invisibility in literature, trying to promote the Soft Operational Research as a legitimate Operational Research discipline. With a very close number of citations, Franco & Montibeller (2010) perform a literature review on facilitated modeling, a traditional tool in PSM interventions; and Ackermann, (2012) discusses arguments in favor of and against the use of PSMs.

4 Applications and Methodological and Theoretical Advances

4.1 PSMs in practice

To present the areas in which the PSMs were applied in the case studies, the papers were classified into five categories: business management; environmental management; healthcare sector; social issues; and other areas

4.1.1 PSMs in business management

From 212 case studies, 67 of them (~32 %) applied PSMs in business management. These papers use PSMs to structure problems about different themes of business management, such as supply chain management, knowledge management, innovation management, organizational strategy, information security, cost management, stakeholder management, support decision-making, change management, and other issues related to business management. Most of the papers (~66% or 44 papers) used SSM, applied individually, or integrated with other methods. Table 3 presents the themes in which the PSMs were applied in business management and the corresponding papers.

Table 3: PSMs in business management

Application Area	Theme	Papers
Business management	Supply chain management	(Behera et al., 2015; J. Davis et al., 2010; Erkoyuncu et al., 2016; Guarnieri et al., 2016; Hanafizadeh & Vali Zadeh, 2015; Hildbrand & Bodhanya, 2017; Irani et al., 2018; Mello et al., 2017; Sharif et al., 2014; Shoushtari, 2013; Tavella & Hjortsø, 2012)
	Knowledge management	(Hanafizadeh & Ghamkhari, 2019; Jianmei, 2010; Klapalová, 2019; Preece & Shaw, 2019; Somerville et al., 2019)
	Innovation management	(Burnett, 2012; Savage et al., 2019; Scozzi et al., 2017; Sjögren et al., 2018; Sossa et al., 2016; Tura et al., 2017; Turner et al., 2017; Zahedi et al., 2018)
	Organizational strategy	(Abuabara et al., 2018; Bryant et al., 2011; Espinosa et al., 2015; L. Houghton, 2013; L. Houghton & Tuffley, 2015; Liboni et al., 2015; Liu et al., 2012; Sauser, Li, et al., 2011)
	Information security	(Damenu & Beaumont, 2017; Schatz & Bashroush, 2018)
	Cost management	(Ameyaw & Alfen, 2018; Erkoyuncu et al., 2014; Fregonara et al., 2016; Urquhart & Whyte, 2018; F. K. Wang & Chen, 2012)
	Stakeholder management	(Andayani, 2017; Broadhurst, 2018; Dias et al., 2016; Eskafi et al., 2019; Phi et al., 2014; Proches & Bodhanya, 2015; W. Wang et al., 2015)
	Support decision-making	(Cristofaro, 2017; Damart, 2010; Ngai et al., 2012; Schotten & Morais, 2019)
	Change management	(Donaires & Martinelli, 2019; Harwood, 2012; Scholz et al., 2020)
	Other issues related to business management	(Bernardo et al., 2018; Burger et al., 2019; Carlucci et al., 2018; Castellini & Paucar-Caceres, 2019; Nakakawa et al., 2013; Niu et al., 2011; Parchami Jalal & Shoar, 2019; Paucar-Caceres et al., 2016; Rodriguez-Ulloa, 2018; Small & Wainwright, 2014; Staadt, 2015; Walworth et al., 2016; F. K. Wang & Chen, 2014; Yu & Hong, 2016)

4.1.2 PSMs in environmental management

Among the case studies, 36 papers (~17 %) apply PSMs in the area of environmental management, particularly in marine ecosystem management, water resource management, environmental conflict, climate change, floods, forest management, waste management, and other environmental issues. Most of these studies (41.2% or 15 papers) used SSM and its variations applied individually or integrated with other methods. Another PSM that is often used in the environmental management context is the DPSIR and its variations, applied individually or integrated with other methods. Table 4 presents the applications of PSMs in environmental management.

Table 4: PSMs in environmental management

Application Area	Theme	Papers
Environmental management	Marine ecosystem management	(Alexander et al., 2015; Baldwin et al., 2016; Gregory et al., 2013; Potts et al., 2015)
	Water resources management	(Dolbeth et al., 2016; Gomes et al., 2018; Harwood, 2018; Hassenforder et al., 2015; Hosseini & Rezaei, 2013; Jafary et al., 2018; López et al., 2019; Pereira & Morais, 2020; Robinne et al., 2018; Sani et al., 2019; Schramm & Schramm, 2018; Unalan, 2013; Zare et al., 2019)
	Environmental conflict	(Hart & Paucar-Caceres, 2014; Slotte & Hämäläinen, 2015; Watkin et al., 2012)
	Climate change	(Beall & Brocklesby, 2017; Freeman & Yearworth, 2017; A. Grant et al., 2019; Hu & He, 2018; Nolan & Crowe, 2010)
	Floods	(Giordano et al., 2017; Santoro et al., 2019; Suriya & Mudgal, 2013)
	Forest management	(Santos et al., 2019; Tikkanen et al., 2016)
	Waste management	(Sankaran et al., 2015; Shaw & Blundell, 2010; Souza et al., 2015)
	Other environmental issues	(Kish et al., 2016; Nathwani et al., 2019; T. T. N. Nguyen et al., 2019)

4.1.3 PSMs in the healthcare sector

32 papers (~15 %) applied PSMs in the healthcare sector to improve the service in health organizations, to support the formulation of public health policies, and other issues related to management in the healthcare sector. In only four cases other PSMs instead of SSM were used (Duryan et al., 2015; Lins et al., 2019; Rees et al., 2018; Robinson et al., 2014). The majority (87.5%) used SSM and its variations applied individually or integrated with other methods. A

recent study presents arguments for the use of PSM in the healthcare sector (Augustsson et al., 2019b), and another argue the need to conduct a review of PSM interventions in this sector (Augustsson et al., 2019a). Table 5 presents the applications of PSMs in the health care sector.

Table 5: PSMs in the healthcare sector

Application Area	Theme	Papers
Healthcare sector	Improve the service	(Carter et al., 2019; Crowe et al., 2017; Dalkin et al., 2012; Duryan et al., 2015; M. Emes et al., 2017, 2019; Hayward et al., 2019; Heyrani et al., 2012; Hodges et al., 2012; Keeffe & Ormsby, 2015; Kotiadis et al., 2013, 2014; Lamé et al., 2019; Newell et al., 2017; Pentland et al., 2014; Price, 2016; Price & Lau, 2013; Rees et al., 2018; Robinson et al., 2014; Schwartz et al., 2017; Sinclair et al., 2014; Small & Wainwright, 2018; Thomas et al., 2014; Torlak & Müceldili, 2014; Železnik et al., 2017)
	Formulation of public health policies	(Lins et al., 2019; Vandenbroeck et al., 2014)
	Other issues related to management in the healthcare sector	(Cardoso-Grilo et al., 2019; Hales & Chakravorty, 2016; Sepehrirad et al., 2017; Sharma et al., 2019; Zheng et al., 2019)

4.1.4 PSMs in social issues

30 papers (~14 %) were identified in which PSMs were used for addressing social issues: teenage pregnancy, insecurity, democracy, small farming, access to food, promoting peace; urban planning, community development, among other social issues. Eight of these studies make mention of the term "Community Operational Research", which Midgley et al. (2018) defined their characteristics. As for the method, SSM is the most frequently used but other traditional PSMs appear such as SCA and cognitive mapping techniques. Table 6 presents the applications of PSMs in social issues.

Table 6: PSMs in social issues

Application Area	Theme	Papers
Social issues	Teenage pregnancy	(Franco & Lord, 2011)
	Insecurity	(Rodríguez-Ulloa et al., 2011)
	Democracy	(Laouris & Michaelides, 2018; Weaver et al., 2018)
	Promoting peace	(Pinzon-Salcedo & Torres-Cuello, 2018)
	Access to food	(Y. Wang et al., 2018)
	Small farming	(Setianto et al., 2014)

	Urban planning	(Capolongo et al., 2019; Coelho et al., 2010; Howick et al., 2017; Jeppesen, 2011; Konsti-Laakso & Rantala, 2018; Lopes et al., 2015; Ninan et al., 2019; Paucar-Caceres et al., 2020; Picchianti, 2019; Todella et al., 2018; White et al., 2016)
	Community development	(Brocklesby & Beall, 2018; Espinosa & Walker, 2013; Henao & Franco, 2016; Hindle & Vidgen, 2018; McLellan & Blanchard, 2018; M. J. Taylor et al., 2012; Trutnevyte et al., 2012; Ufua et al., 2018; Xing et al., 2013)
	Other social issues	(Hardjosoekarto, 2012; Nakagawa et al., 2010; Tavella & Papadopoulos, 2015b)

4.1.5 Other areas

Other areas that appeared in the case studies were public management, military management, non-profit organizations, teaching and research, systems design, among other issues. In this category, there are a total of 47 articles (~ 22%). As in other categories, SSM is the most frequently applied PSM. Table 7 presents the application of PSMs in other areas.

Table 7: PSMs in other areas

Application Area	Theme	Papers
Other areas	Public management	(Eigbe et al., 2010, 2015; Fitch et al., 2012; Ison et al., 2014; Jetha et al., 2019; Norese et al., 2015; Rouwette et al., 2011; Sauser, Mansouri, et al., 2011)
	Military management	(Cloutier et al., 2015; Lowe et al., 2016; Van Antwerpen & Curtis, 2016; Veldhuis et al., 2015)
	Non-profit organizations	(Armstrong, 2019; Moore et al., 2017; Strang, 2019)
	Teaching and research	(Bell et al., 2017; Booton, 2018; Carr et al., 2010; Cezarino et al., 2016; de Almeida et al., 2019; Hardman & Paucar-Caceres, 2011; Holland & Garfield, 2016; Luke Houghton & Stewart, 2017; Mirijamdotter et al., 2018; Radfar et al., 2019; Siddiqui et al., 2016; D. Taylor et al., 2015; Wallis, 2020; S. Wang & Wang, 2016; Wilkin & Underwood, 2016; Yearworth & Edwards, 2014)
	Systems design	(M. R. Emes et al., 2012; Fountas et al., 2015; Hanafizadeh & Aliehyaei, 2011; Paes de Faria et al., 2020; Rose & Saifullah, 2012)
	Science and technology conflict	(Cronin et al., 2014)
	Buddhist organizations	(Shen & Midgley, 2015)
	Eldercare	(Sommer & Mabin, 2016)

Rocket Launch	(Caruzzo et al., 2015)
Dressage	(West & de Bragança, 2012)
Mass Media	(Hardjosoekarto et al., 2014)
5G technology	(Jones et al., 2016)
Tourism	(Yeoman et al., 2016)
Crisis management	(Grunnan & Fridheim, 2017)
Service-Dominant Logic	(Glassburner et al., 2018; Nowicki et al., 2018)

4.2 Methodological and theoretical advances

To present the methodological and theoretical advances, the analysis was separated into five topics: development of new approaches, aspects of interventions, multimethodologies, community operational research, and recognition of PSMs.

4.2.1 Development of new approaches

Recent advances were made in the development of new approaches for dealing with complex problems. Fountas et al. (2015) proposed an SSM-based conceptual model to analyze the development of an agricultural information management system. Tako & Kotiadis (2015) proposed a multimethodology model that combines optimization techniques with SSM to support discrete-event simulation in the health care sector. Yearworth & White (2013) described a method for exploring the creation of causal loop diagrams from coding trees that are developed through a Grounded Theory approach. Jun et al. (2011) provided a tool to support healthcare managers comparing and choosing appropriate simulation and modeling techniques. Georgiou (2012) shows how SODA can be integrated with SSM and applied in a more broad way. Midgley & Pinzón (2011) argue that the Theory of Boundary Critique is useful for conflict prevention and presents a model to reinforce their arguments. Han & Laiô (2011) presented an approach for planning analysis based on the combination of the garbage-can model, SCA and decision tree. Fregonara et al. (2013) showed an SCA-based approach for selecting, designing, and evaluating sustainable building solutions. Müller et al. (2012) proposed an approach to guide the setting up of groups in collaborative research involving social problems. Cunha et al. (2016) presented a procedure to support analysts in aggregating cognitive maps.

Scattoni (2018) describes an approach based on SCA to construct urban planning rules. Keršulienė et al. (2010) feature a method, named Step-Wise Weight Assessment Ratio Analysis

– SWARA, for solving disputes. Ganzert et al. (2012) presented an approach based on VSM and SSM to prospect, select, and distribute information across organizations. Michnik, (2013) describes a method for dealing with complex situations (Weighted Influence Non-linear Gauge System- WINGS). Dortmans & Durrant (2013) presented an approach based on SSM to address the issue of successful changes in complex organizations. Shaw & Blundell (2010) developed a methodology (WASAN) that aims to support industry managers to develop recommendations for waste reduction. Mota-Hernández et al. (2015) proposed an SSM-based approach to identify and examine the dynamics of global financial and economic markets. Paucar-Caceres & Jerardino-Wiesenborn (2019) presented a framework with the objective of refining and improving the understanding of the SSM application process. . Other approaches that aim to structure complex problems are described in the following papers: Ferreira (2013); D. B. Grant & Elliott (2018); Hanafizadeh et al. (2018); Lauttamäki (2016); Lombardi (2018); Pepper et al. (2016); and Torres (2018).

Methodological issues of PSMs are also addressed in some review papers: Franco & Montibeller (2010) discussed facilitated modeling as an intervention tool and offer a formal definition for it; Ranyard et al. (2015) discussed the influences of Business Analytics and PSM in the future of Operational Research.

4.2.2 Aspects of interventions

In the last ten years, some studies have examined how facilitated modeling environments work in practice: Bell & Morse (2013); E. A. J. A. Rouwette (2011); and Tavella & Franco (2015). Cunha & Morais (2016, 2019) analyzed the implications of PSM intervention in group decision-making processes. Franco & Rouwette (2011) examined the dynamics of facilitated modeling workshops. Franco et al. (2016) sought empirical evidence for the influence of cognitive factors in interventions. White (2016) provided a framework for understanding behavior in Operational Research interventions. Tavella & Lami (2019) explored how negotiations evolve in a PSM intervention. Zec & Matthes (2018) offered insights about virtual interventions. Yearworth & Cornell (2016) presented a framework to make the modeling process more effective.

Others explore the role of facilitators (McCardle-Keurentjes & Rouwette, 2018; Tavella & Papadopoulos, 2015a; Tully et al., 2019) and the experiences of participants in PSM interventions (Rouwette et al., 2016; Scott et al., 2013, 2016a). Velez-Castiblanco et al. (2016) used the Boundary Game theory to understand the social dynamics underlying the design of an

intervention. Other aspects of the interventions are studied in Franco & Greiffenhagen (2018); and Lami & Tavella (2019). According to White (2016), on a practical level, the study of interventions has been done through the lens of the Behavioral Operational Research.

4.2.3 Multimethodology

An important area of discussion about PSMs is mixing methods, the so-called multimethodology. Herrera et al. (2016) can be quoted, who presented insights on the benefits and drawbacks of multimethodology. Zhu (2011) discusses multimethodology. Howick & Ackermann (2011) reviewed the mixing of methods in Operational Research. Marttunen et al. (2017) reviewed the combination of Multi-Criteria Decision Analysis and PSMs. In addition to these theoretical papers, the wide application of multimethodologies in case studies and in the new approaches presented above can be noted.

4.2.4 Community Operational Research

Rosenhead (2006) pointed out that a fruitful application area for PSMs would be the Community Operational Research. In 2018, the European Journal of Operational Research dedicated an edition to Community Operational Research, in which this area is presented in theory and in practice. Some examples of papers that address Community Operational Research are Espinosa & Walker (2013); Gomes et al. (2018); Midgley et al. (2018); Ufua et al. (2018)

4.2.5 Recognition of PSMs

Although PSMs have been discussed in literature for more than 50 years, we observe that efforts are still being applied to increase the recognition and acceptance of PSMs in the Operational Research community. Ackermann (2012) discusses arguments in favor of and against the use of PSMs. Champion & Wilson (2010) discussed contingency factors that influence the validation of PSMs. Franco (2013) discusses the benefits related to knowledge creation in Soft Operational Research interventions. Dodd (2019) addresses the difficulty of Operational Research to adopt more relational forms of modeling. Midgley et al. (2013) described a methodological framework that aims to evaluate and compare PSMs interventions. Mingers (2015) discussed how Operational Research and Management Science can contribute to solving real problems and concludes that structuring problems can contribute a lot to this Mingers & White (2010) reviewed the contribution of Systems Thinking to Operational Research in the first decade of the 2000s. Mingers (2011) provided a discussion on the recognition of Soft Operational Research as a legitimate Operational Research discipline. To

define what constitutes a PSM, Smith & Shaw, (2019) present a framework for determining which approaches can be considered PSMs.

5 Discussion

In this section, the main findings of this research are presented and some directions for future work on this topic.

5.1 Evolvement of the research on PSMs

It was observed that the number of publications on PSMs has been increasing annualy and are wiedely distributed in a large number of journals that encopasse issues on different knowledge areas: in the first years of the decade (2010 to 2014), the average of publications per year was ~21 and in the last years of the decade this number jumped to ~40, a growth of ~100% in the number o publications spread throughout 128 different journals.

However, most of the publications come from studies that were developed in Europe, particulary England where the movement for a reevaluation of the OR started. While, there are 117 papers coming from England, the United States, which is giant in scientific research, are responsible for only 37 papers of the sample. From the list of ten authors with the highest number of publications in the reviewed papers, seven are affiliated to European universities, six from in Universities in the United Kingdon: Mike Yearworth, Leroy White, Alberto Paucar-Caceres, John Mingers, L. Alberto Franco, and Gerald Midgley. Besides theses authors, the chief PSMs have been developed by researchers affiliated at UK Universities: SSM was developed by Peter Checkland, a Professor at Lancaster University; SODA, which initially was developed by Colin Eden and colleagues at Bath University; and SCA, which initially was developed by John Friend and colleagues at the Tavistock Institute of Human Relations.

Among these main PSM researchers, Alberto Paucar-Caceres has been collaborating with Brazilian academics, which appears in the list of the six countries that have the highest number of publications, with 19 publications of the sample of the reviewed papers. Besides England, United States and Brazil, Australia also appears in this list with 41 publications, Italy with 21 publications, and New Zealand with 20 publications. In Australia, Fran Ackerman was highlighted who is co-author of the SODA PSM.

The European Journal of Operational Research was the journal with the largest number of publications (~18), it isone of the most important peer-reviewed journals on the area of OR, founded by the Association of European Operational Research Societies (EURO), and whose

editor in chief is Roman Słowiński from the Poznan University of Technology, Institute of Computing Science, in Poland.

5.2 Applications

Most of the reviewed papers present applications of PSMs addressing business management problems, encompassing issues on supply chain management, knowledge and innovation, organizational strategy, information security, costs, etc.However, the review showed us PSMs are powerful tools for solving unstructured problems from different nature, such as environmental management, healthcare management, social issues, and others

The PSM SSM (by itself or in combination with other methods) is the most frequently used PSM in these applications. Moreover, SSM is the most referenced PSM of all the types of studies concerning this topic. This is shown in the keyword co-occurrence network, in which the most cited keyword is Soft Systems Methodology, and in the co-authorship network, where Peter Checkland, its creator, appears as the second most cited author in the sample of reviewed papers.

The SSM consists of a process with seven stages, for which a small set of requirements is given, offering high practitioner freedom. This makes the application of SSM very simple and easy and so attractive to be used. However, it is important to note that SSM is a framework that integrates individuals, usually conflicting with each other, to construct a commom understading about a complex situation aiming to solve it. Thus, the simplicity of its requirements contrasts with the complexity of the issues that can emerge in each of its stages. A consequence of this isto ensure effective results, we should have a very experienced analyst moderating the application of the SSM; othewise, the results can be questionable, puttting the effectivness of the PSMs at risk.

The high popularity of SSM among the PSMs might induce the mistake of thinking that PSMs and SSM are the same things. Moreover, despite the efforts that are applied to give the desired position to PSMs in the Operation Research area, it is also observed that “PSMs club ” is very closed, including basically only three methods (SSM, SODA, and SCA). Meanwhile, various other methdods and techniques are being developed and successfully applied for structuring complex problems. In this sense, the OR’s community should come together to answer the question “*What is a PSM?”* .

Attempts to answer this question have been made: Smith & Shaw (2019) proposed a framework to determine what approaches can be considered PSM and according to them only

SSM, SCA, and SODA are PSMs. Using the framework proposed by Smith & Shaw (2019), Harwood (2019a) states that VSM is a PSM. Bell, (2012) discusses whether the DPSIR is a PSM and argues that, although limited, when DPSIR is used in combination with other methods it can perform as a PSM. Therefore, we understand that the lack of a definition for PSMs, that incorporates the philosophy underlying of the structuring of problems, ends up limiting the progress of these methods, but it is not necessary a consensual definition. A kickoff was done by Yearworth & White (2014) that developed a set of testable propositions to recognize PSMs even when this method is not classified as such.

5.3 Theoretical and methodological advances and emerging topics

Some of the reviewed papers aim to provide methodological and theoretical advances in approaches for dealing with complex unestructured problems. In this sense, we noted that the combination of a PSM with other techniques and methods, the so called multimethodology, is an emeerging topic. In contrast to the Hard-OR methods, these PSM-based multimethodologies aim to adapt the method to the problems and not the contrary. Therefore, it can be concluded that the motivation that gave rise to these methods more than 50 years ago still remains the same, that is, the focus must be on the problem and not the method or technique.

It was also observed that efforts are still being applied to reduce the negative perception that the OR community has about PSMs. For example, papers were found that examine modeling environments, implications of PSM intervention in the group decision-making processes, the role of facilitators and the experiences of participants. Finally, it was observed that the studies involving the development and applications of PSMs have a close connection to Behavioral Operational Research, which is a new area of specialization whose focus is to study human behaviors and emotions when facing complex decision problems and that have sparked interest in academic and practitioners from OR as well as from other disciplines.

6 Conclusion

The goal of this paper was to analyze the relevant empirical and theoretical literature about PSMs published over the last decade (2010-2020) aiming to verify the distribution of papers according to year, journals, countries, and authors; to identify the most frequent PSMs and areas of application; and to present methodological and theoretical advances, and emerging topics.

It can be concluded that PSMs have gained popularity worldwide, but studies are still mainly concentrated in the community of OR in Europe, particularly in the United Kingdom.

Efforts are necessary to propagate PSMs into the United States and Asia's OR communities as well as in other disciplines since complex problems are commonplace in human and social relations. Regarding the application of PSMs, it can also be concluded that PSMs are powerful tools for solving problems from different areas, particularly the ones related to environmental and social systems.

As far as methodological and theoretical advances are concerned, we encourage the OR community to apply effort to review the defition of PSM, aiming to make it wider in order to include other existing methdods and techniques for structuring complex problems. Moreover, it can be observed that multimethodology approaches for dealing with complex unestructured problems is a trendy topic and that this can help to increase the intereset of OR`s academics and practitioners on PSMs. Finally, the consolidation of the Behavioral Operational Research area may have positive impacts on PSMs since both areas are closely connected.

Thus, the development and applications of PSMs is a research topic that is in a growth stage with a large quantity of opportunities to be explored and this paper can be used as a starting point to new development in this field.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES).

References

Observation: The list of references is at the end of this document.

CHAPTER 3

SECOND PAPER

Problem Structuring Methods in Social-Ecological Systems

Problem Structuring Methods in Social-Ecological Systems[2]

Abstract

Social-ecological systems (SES) are interfaces formed by social and ecological systems. It is understood, therefore, that complexity is one of its features, and problematic situations in these systems are common. In Operational Research, there is a class of approaches that were created to lead with complex unstructured problems, which are the Problem Structuring Methods (PSMs). These approaches seek to generate a shared understanding of these situations from the perception of the involved parties, that is, the objective is to structure the problem before solving it. And this is necessary because goals are not clear, actors are diverse and have different perspectives, interests are conflicting, and uncertainties are common in these situations. In short, SES problems are complex. Thus, given the characteristics of the systems and these approaches, the goal of this paper is to investigate the use of Problem Structuring methods in Social-Ecological Systems. To achieve it, we provided a literature review with 21 studies published in peer-reviewed journals over the last decade. This study contributes to identify the geographic location of the application, PSMs used, application contexts, the techniques for collecting the input data, types of participants, inputs, and outputs of the models, in addition to the main benefits and limitations of the models. It is concluded that PSMs are suitable for problems faced in SES, but the application of these approaches in these contexts is still small and should be encouraged.

Keywords: Problem Structuring Methods (PSMs). Soft Systems Methodology (SSM). Strategic Choice Approach (SCA). Strategic Options Development and Analysis (SODA) Social-ecological systems (SES).

1 Introduction

Complex unstructured problems are characterized by the existence of various actors, different perspectives, conflicting interests, significant intangibles, perplexing uncertainties, and complexity (Rosenhead, 2006). Mingers (2011) adds the following characteristics: absence of reliable data, disagreement about the nature of the problems, which are strategic and quite common.

Approximately 50 years ago, a set of approaches (methodologies, methods, and tools) have been developed to deal with this type of problems for which traditional methods of Operational Research cannot deal. In the Operational Research community, these methods are known as Problem Structuring Methods (PSMs), and the best-known and applied are Soft Systems Methodology (SSM) (Checkland, 2001), Strategic Choice Approach (SCA) (Friend,

[2] Authorship: Alexandre de Araújo Gomes Júnior & Vanessa Batista Schramm, submitted to Environmental Modelling and Software (Qualis CAPES: A1) on November 10, 2020.

2001), and Strategic Options Development and Analysis (SODA) (Ackermann & Eden, 2001; Eden & Ackermann, 2001).

Although they have existed for about half a century, among researchers and practitioners, there is no consensus on what is a PSM and which methods are PSMs (Ackermann, 2012). In the literature, there are different definitions of PSMs and attempts to resolve these issues were made in Smith & Shaw (2019), and Yearworth & White (2014). The consensus is that PSMs are intended to structure complex problems, whose characteristics are listed above. Moreover, PSMs should encourage dialogue among participants to converge on a common understanding of the problem that will help the group to achieve a joint agreement and generate commitments to resolve the situation (Mingers & Rosenhead, 2004; Mingers & White, 2010).

In this sense, the list of existing PSMs can be expanded to include the following approaches: Decision Structuring Dialogue (DSD) (Slotte & Hämäläinen, 2015), Drivers, Pressures, State, Impact and Response (DPSIR) (Bell, 2012), Fuzzy Cognitive Mapping (FCM) (Giordano et al., 2017; Santoro et al., 2019), Viable System Model (VSM) (Beer, 1984), and Waste and Source-matter Analyses (WASAN) (Shaw & Blundell, 2010) to name a few.

The PSMs have been used in different contexts such as business management (Abuabara et al., 2018; Hanafizadeh & Ghamkhari, 2019; Schatz & Bashroush, 2018), environmental management (Gomes et al., 2018; Hart & Paucar-Caceres, 2014; Schramm & Schramm, 2018), healthcare sector (Carter et al., 2019; M. Emes et al., 2019; Lamé et al., 2019), social issues (Franco & Lord, 2011; Laouris & Michaelides, 2018; Pinzon-Salcedo & Torres-Cuello, 2018), and other contexts (Armstrong, 2019; Caruzzo et al., 2015; Cloutier et al., 2015).

Ackermann (2012) lists some benefits resulting from using PSMs: complexity management that aims the participants to understand the problem holistically, which is a necessary condition for making proper changes in the system; multiple perspectives are considered, which gives participants the feeling of belonging in the decision-making process, and consequently increase the commitment of the group; reduction of communication failures; make possible to all participants to observe how their ideas relate to those of others. Rosenhead, (2006) adds the supporting to subjectivity and differences and acceptance of non-quantitative uncertainties.

Given this, we believe that PSMs are powerful tools to be applied in context of Social-Ecological Systems (SES). Although there is no unifying definition for SES (Colding & Barthel, 2019). Anderies et al. (2004) define SES as an ecological system affected and linked

by one or more social systems. Cumming (2014) informs that SES is used to describe an integrated system of people and nature, in which feedbacks occur between the elements of each of these systems.

Given this, the goal of this paper is to investigate the use of Problem Structuring Methods in Social-Ecological Systems, focusing on three dimensions of analysis (i) overview, which includes geographical location, type of PSM used, and application context; (ii) characteristics of the models, which aim to identify the approaches used for collecting input data, types of participants, inputs, and outputs of the models; and (iii) the results dimension to analyze the main benefits and limitations of the models. The remainder of this paper is organized as follows: Section 2 presents the research method; Section 3 presents the material evaluation; Section 4 shows the discussion; and the conclusion is presented in Section 5.

2 Research method

To perform the review, the Content Analysis technique (Brewerton & Millward, 2001) was used, applying the four-step iterative process proposed by T. Nguyen et al. (2018):

- 1st step - Material collection: at this step, we conducted a structured process for searching and delimitation of the base of papers that will be reviewed.
- 2nd step - Descriptive analysis: in the descriptive analysis, we present the dynamic of the publications in terms of distribution of publications over the years and journals.
- 3rd step - Category selection: at this step, it was constructed a framework to systematize the literature review, which is formed by a set of structural dimensions and their analytical categories.
- 4th step - Material evaluation: analysis of papers based on the proposed classification framework.

2.1 Material collection

For searching the papers, we use the Web of Science™ Core Collection (WoS), which is one of the broadest databases of quality journals (Powell & Mustafee, 2017), with over 1.7 billion references cited from more than 159 million records (Clarivate, 2020). The keywords used in the search are: "problem structuring method*" or "soft systems methodology" or "strategic choice approach" or "strategic options development and analysis". We chose to search by topic that searches for the keywords in the following fields of the paper: title, abstract,

authors' keywords, and keywords plus. Table 1 presents the parameters of the search that was performed in February 2020.

Table 1: Web of Science™ search parameters

Parameter	Input
Database	Web of Science™ core colletion
Indexes	Science Citation Index Expanded (SCI-EXPANDED); Social Sciences Citation Index (SSCI); e Emerging Sources Citation Index (ESCI).
Search type	Basic search
Field Labels	Topic
Keywords	"problem structuring method*" or "soft systems methodology" or "strategic choice approach" or "strategic options development and analysis"
Document Type	"Article" or "review".
Period	2010-2020
Languages	English

This search returned 332 documents. Firstly, the abstracts of these 332 papers were submitted to a preliminary analysis to select those that presents empirical cases of PSMs applications in the Environmental Management. With this fist filter, 36 papers were selected and submitted to full reading to identify those that met the following criteria, simultaneously: (1) presence of an ecological system, (2) presence of a social system, (3) interaction between these systems, and (4) interested parties participation in the interventions. The goal of this second filter was to remove papers that were not concerned with SES. At the end, 15 papers were excluded from the database and we proceed with the analysis of 21 papers. Figure 1 shows the detailed process for identifying the papers that were analyzed in this review.

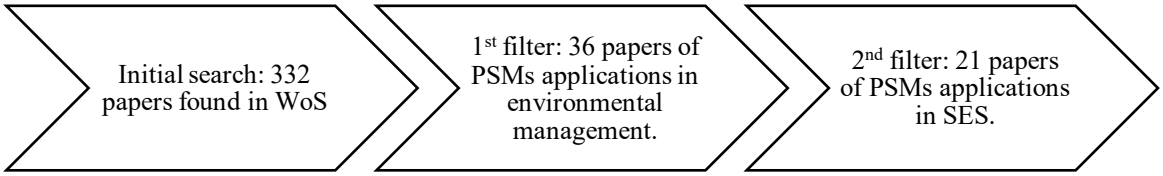

Figure 1: Material collection process

2.2 Descriptive analysis

Figure 2 presents the distribution of the papers over the years, from 2012 to 2020. Although the search period chosen started in 2010, the first revised paper was published in 2012. We can see that 2019 is the year in which there is the largest number of papers that apply PSMs in SES (6 papers, ~29%). This may indicate an increased interest on the part of researchers and practitioners in applying these methods to structure complex problems in these

contexts. The reduced number of papers in 2020 can be explained due to the date of the search in the database (February 2020).

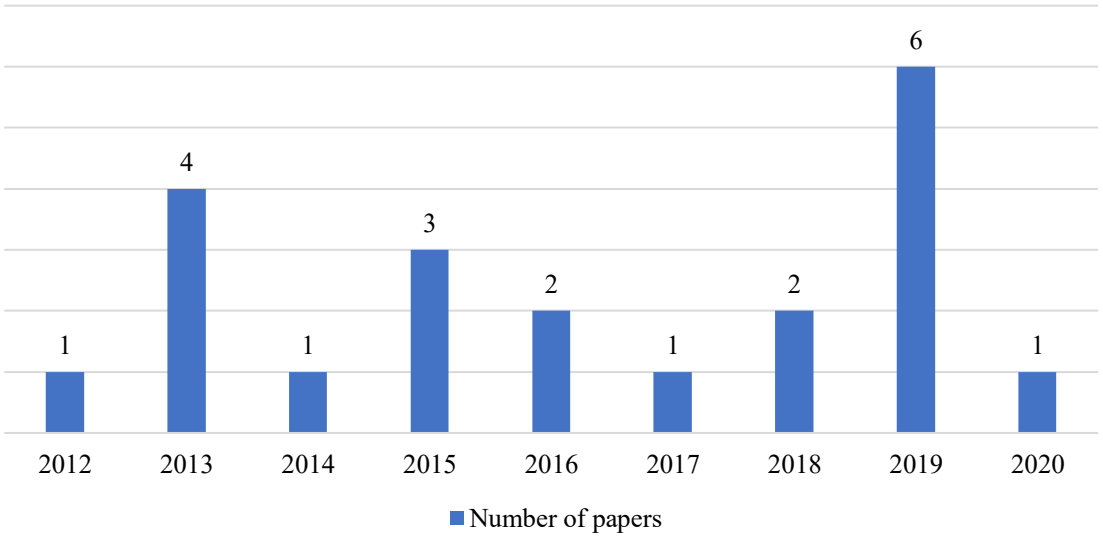

Figure 2: Distribution of papers per year (2012-2020).

Regarding journals, the reviewed papers were published in 16 different journals, the four with the most papers are: Systemic Practice and Action Research (3), Water Resources Management (2), European Journal of Operational Research (2), and Ecology and Society (2). Figure 3 illustrates the distribution of the papers by journal.

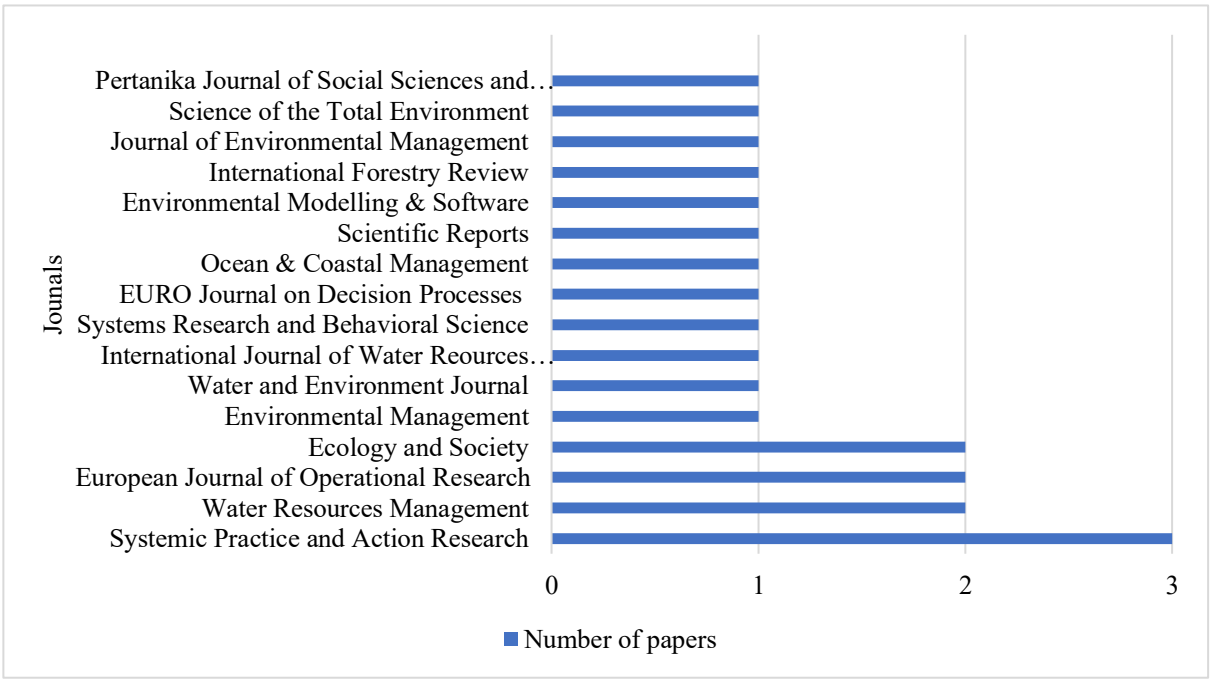

Figure 3: Distribution of reviewed papers per journal

2.3 Category selection

This step aims to build a framework formed by structural dimensions and analytical categories that systematize this literature review. By reading the papers, we identified three structural dimensions: overview of the cases, characteristics of PSM-based models, and results. Analytic categories were derived from a previous study that analyzed problem structuring in participatory forest planning (Khadka et al., 2013). Table 2 shows and describes the structural dimensions and analytical categories.

Table 2: Literature review framework

Structural dimension	Analytic categories	Description
Overview of the cases	Geographical location	Application location: continent and country or region
	PSMs used	Methods used in the paper
	Application context	SES in which the PSM was applied occurred
Characteristics of PSM-based models	Input gathering	Approaches used for collecting input data
	Types of participants	Characterization of the participants in the models
	Inputs	Inputs data for the models
	Outputs	Results of the models
Results	Benefits	Benefits of the models
	Limitations	Limitations of the models

3 Material evaluation

In this section, the reviewed papers were analyzed according to the classification proposed on the framework described above (Table 2).

3.1 Overview of the cases

3.1.1 Geographical location

PSMs applications are geographically distributed in Europe with eight papers (Alexander et al., 2015; Dolbeth et al., 2016; Giordano et al., 2017; Gregory et al., 2013; Potts et al., 2015; Santoro et al., 2019; Slotte & Hämäläinen, 2015; Watkin et al., 2012), Asia with six papers (Baldwin et al., 2016; Gomes et al., 2018; Hosseini & Rezaei, 2013; Sani et al., 2019; Suriya & Mudgal, 2013; Zare et al., 2019), South America with five papers (Hart & Paucar-Caceres, 2014; López et al., 2019; Pereira & Morais, 2020; Santos et al., 2019; Schramm & Schramm, 2018), and North America with only one (T. T. N. Nguyen et al., 2019). No applications have been found in Africa and Oceania. The study of Unalan (2013) occurred in Turkey, therefore on the European and Asian continents, which together are responsible for ~71% of the studies. However, Brazil is the country with the greatest number of cases (3 cases), followed by the United Kingdom, Spain, and Iran (2 each). Figure 4 shows the geographical location of the reviewed papers.

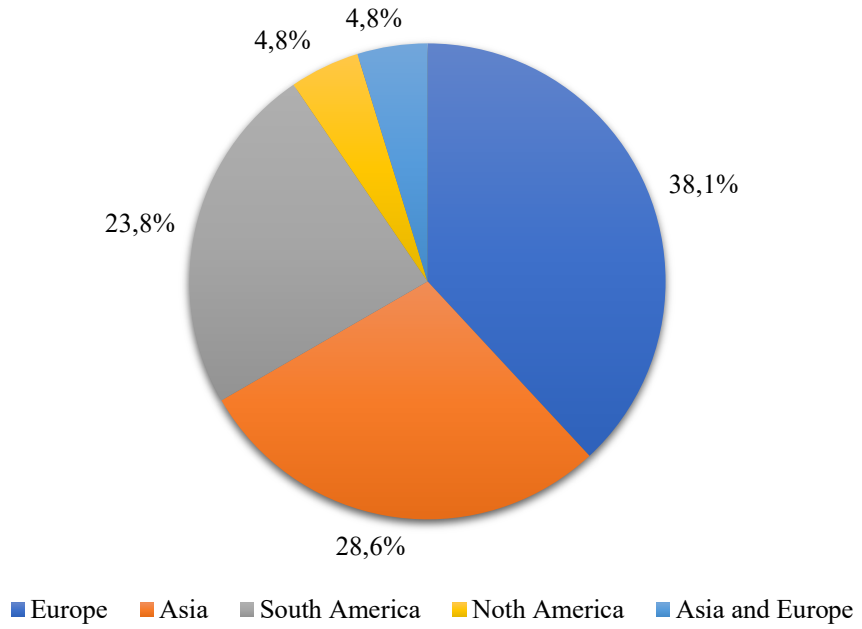

Figure 4: Geographical location

3.1.2 PSMs used

Almost half of applications used the SSM (10 papers): Alexander et al. (2015), Hart & Paucar-Caceres (2014), Hosseini & Rezaei (2013), López et al. (2019), T. T. N. Nguyen et al. (2019), Potts et al. (2015), Sani et al. (2019), Suriya & Mudgal (2013), Unalan (2013), and Watkin et al. (2012). The second most frequently applied PSM is the DPSIR (4 papers): Baldwin et al. (2016), Dolbeth et al. (2016), Gregory et al. (2013), and Zare et al. (2019). Three applications of SODA were found: Pereira & Morais (2020), Santos et al. (2019), and Schramm & Schramm (2018). FCM was applied in two cases: Giordano et al. (2017) and Santoro et al. (2019). Two studies use approaches that can be considered PSMs: Community Operational Approach (COA) (Gomes et al., 2018) and DSD (Slotte & Hämäläinen, 2015). In 43% of the cases, a multi-methodology-based approach was applied: Alexander et al (2015), Giordano et al. (2017), Gomes et al. (2018), Hosseini & Rezaei (2013), López et al. (2019), Pereira & Morais (2020), Santoro et al. (2019), Suriya & Mudgal (2013), and Zare et al. (2019). Figure 5 presents the PSMs used in the reviewed papers.

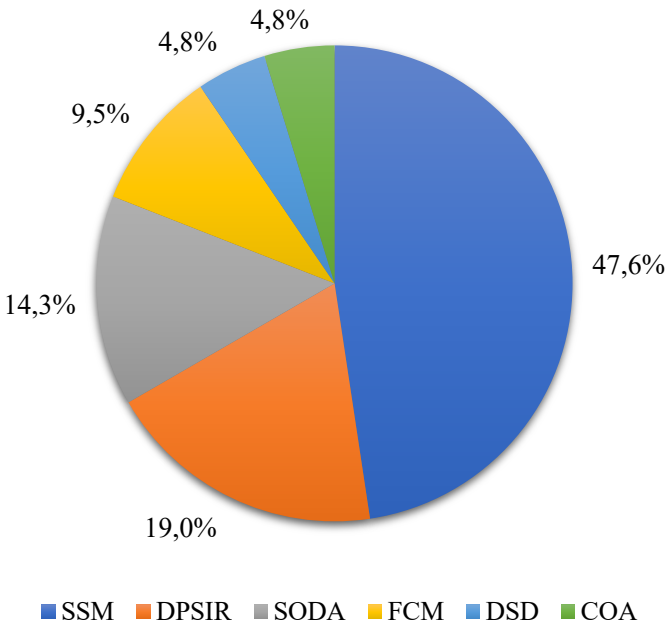

Figure 5: PSMs used

3.1.3 Application contexts

Almost half of the studies applied PSMs for supporting the management of hydrographic basins or groundwater in various complex problems: power generation (Unalan, 2013), supply water (Gomes et al., 2018; Pereira & Morais, 2020; Schramm & Schramm, 2018), information system for sustainable natural resource management (Hosseini & Rezaei, 2013), water resource conservation (López et al., 2019), development of governance systems (Sani et al., 2019; Zare et al., 2019), and impacts of business operations on communities and natural resources (Hart & Paucar-Caceres, 2014; Watkin et al., 2012). There are a set of studies that use PSMs in the context of managing marine or coastal ecosystems (Alexander et al., 2015; Baldwin et al., 2016; Gregory et al., 2013; Potts et al., 2015). PSMs have also been used in flood management (Giordano et al., 2017; Santoro et al., 2019; Suriya & Mudgal, 2013), and management of lakes or lagoons (Dolbeth et al., 2016; Slotte & Hämäläinen, 2015). The studies that do not involve water management address the following contexts: ecological restoration of animals (T. T. N. Nguyen et al., 2019) and forest management (Santos et al., 2019). Figure 6 shows the application contexts.

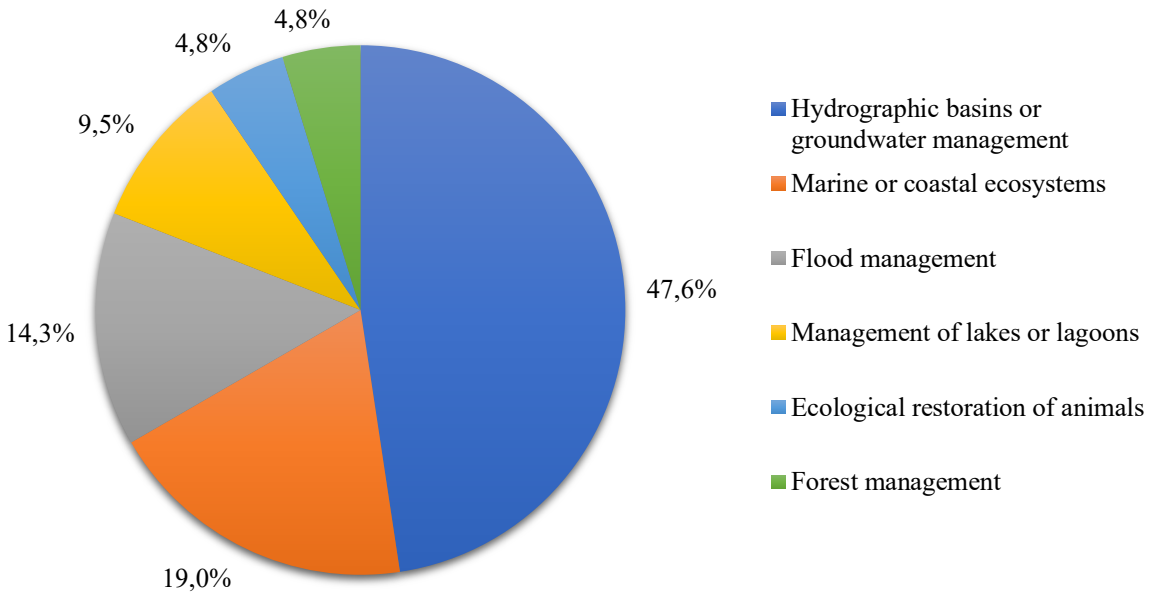

Figure 6: Application contexts

3.2 Characteristics of the models

3.2.1 Input gathering

In approximately half of the reviewed papers (11 papers) a combination of techniques was applied to gather the data necessary to model the complex problems. The following combinations have been identified: workshop and interview (Giordano et al., 2017; Santoro et al., 2019); workshop, interview, and observation (Schramm & Schramm, 2018); workshop, interview, and document analysis (Pereira & Morais, 2020); interview, focus group, and document analysis (Sani et al., 2019); interview, workshop, survey, and field investigation (López et al., 2019); workshop, observation, open discussion, and document analysis (Slotte & Hämäläinen, 2015); interview, observation, field investigation, and document analysis (Zare et al., 2019); interview and document analysis (Unalan, 2013); focus groups and citizen juries (Dolbeth et al., 2016); workshop, interview, open discussion, field investigation, and focus group (Gomes et al., 2018).

Regarding to the other reviewed papers, only one technique was used: workshop (5 papers): (Alexander et al., 2015; Baldwin et al., 2016; Hart & Paucar-Caceres, 2014; Potts et al., 2015; Suriya & Mudgal, 2013), interview (3 papers) (Hosseini & Rezaei, 2013; Santos et al., 2019; and Watkin et al., 2012), observation (T. T. N. Nguyen et al., 2019), and in paper of Gregory et al., (2013), the data used in the structuring came from the paper authors' own understanding of the situation, so no specific data collection technique was identified.

Therefore, we classify the technique used as "other". Figure 7 shows the approaches of input gathering used in the papers.

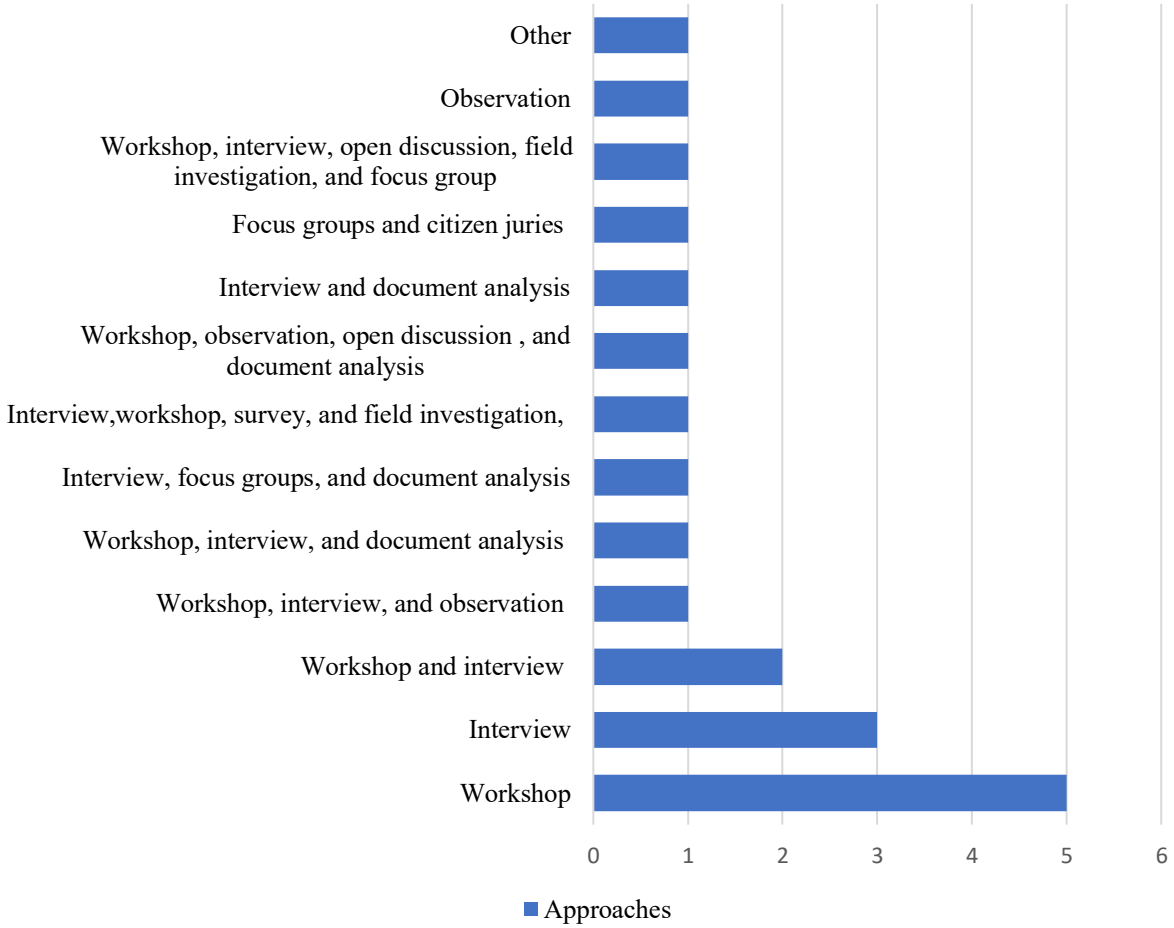

Figure 7: Approaches used for input gathering

3.2.2 Types of participants

We identified four type of representatives: (i) government, which includes representatives of the public power.(ii) private sector, which includes companies and other private organizations representatives; civil society, regarding representatives from communities, NGOs, and others civil actors; and (iv) specialists (scientists and researchers). In 76% of the cases, the groups were heterogeneous with representations from various segments as follows.

In three studies the group was composed by representatives from the government, private sector, civil society, and specialists (Baldwin et al., 2016; Hart & Paucar-Caceres, 2014; Unalan, 2013). A similar group composition, but without specialists, was verified in the studies of Dolbeth et al. (2016), Schramm & Schramm (2018), and Slotte & Hämäläinen (2015). In the study of Watkin et al. (2012), instead of specialists, they did not consider the perspective from

civil society representatives. While in the studies of T. T. N. Nguyen et al. (2019), Sani et al. (2019), Santoro et al. (2019), they did not consider private sector representatives and the group was composed by representatives from the government, civil society, and specialists.

In some studies, only two types of representatives were considered: government and specialists (Santos et al., 2019; Suriya & Mudgal, 2013), civil society and specialists (Hosseini & Rezaei, 2013; Zare et al., 2019), and government and civil society (Giordano et al., 2017; Gomes et al., 2018). Only 24% of the studies, homogeneous participation was verified: civil society (López et al., 2019), specialists (Alexander et al., 2015; Gregory et al., 2013; Potts et al., 2015) and private sector (Pereira & Morais, 2020). Figure 8 shows the types of participants in the reviewed papers.

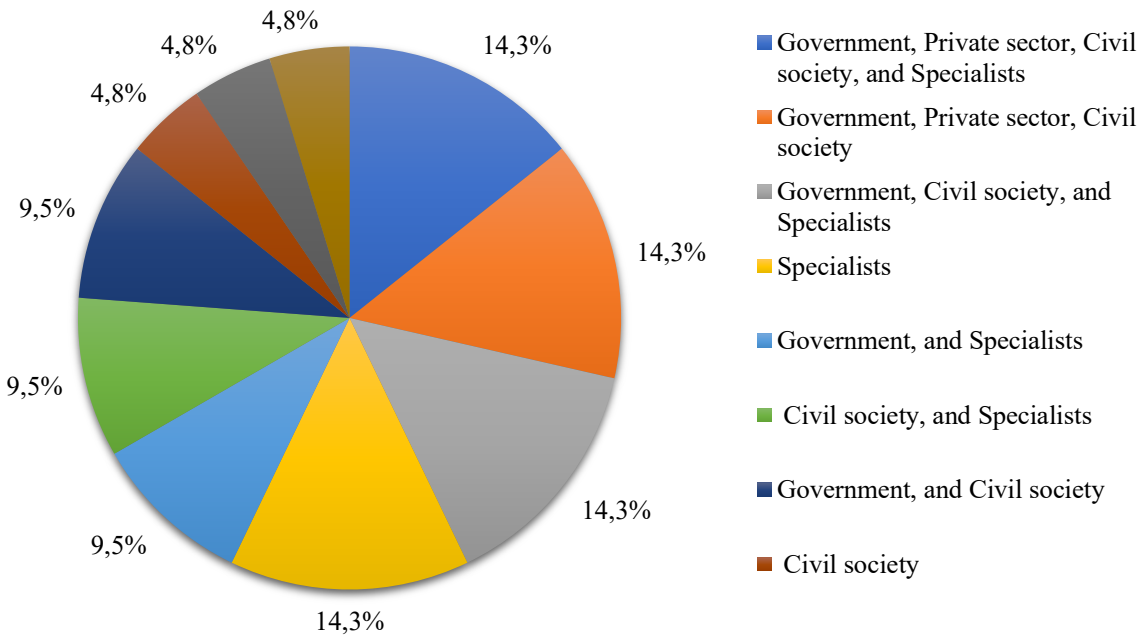

Figure 8: Types of participants

3.2.3 Inputs and outputs of the models

Regarding the type of input for the PSM-based models, the perception of the actors involved in problematic situations was used in all the reviewed papers. However, in five cases (~24%), data from documents were also used combined with actors' perceptions (Pereira & Morais, 2020; Sani et al., 2019; Slotte & Hämäläinen, 2015; Unalan, 2013; Zare et al., 2019).

In order to synthesize the outputs provided by the models, four categories were proposed: (i) conceptual models; (ii) illustrations; and (iii) cognitive maps; and (iv)

frameworks, such as lists, CATWOE analysis, graphics, rakings, game tree, and causal loop diagrams.

In only five studies, the PSM-based models provide only one type of output: conceptual models (Baldwin et al., 2016; Gregory et al., 2013; Sani et al., 2019), and framework (Slotte & Hämäläinen, 2015), and cognitive maps (Santos et al., 2019). In approximately 76% of the cases, the PSM-based models provide more than one type of output. In the following studies, the models provide a combination of conceptual models, illustrations, and frameworks: Hosseini & Rezaei (2013), López et al. (2019), T. T. N. Nguyen et al. (2019), Potts et al. (2015), Suriya & Mudgal (2013), Unalan (2013), and Watkin et al. (2012). Cognitive maps and frameworks are results provided in the studies of Giordano et al. (2017), Pereira & Morais (2020), Santoro et al. (2019), and Schramm & Schramm (2018). Conceptual models and frameworks were the results of the following studies: Alexander et al. (2015), Dolbeth et al. (2016), Gomes et al. (2018), and Zare et al. (2019). The outputs identified in Hart & Paucar-Caceres (2014) were illustration and framework. Figure 9 shows the types of the output provided by the models.

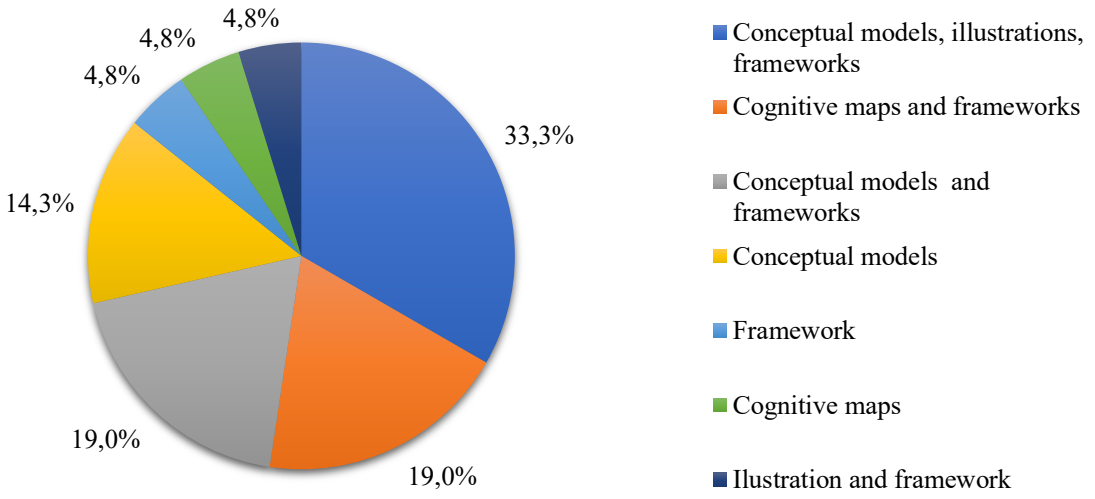

Figure 9: Outputs

3.3 Results

3.3.1 Benefits and limitations of the models

We observed the positive implications of the models considering a practical perspective and we identified the main benefits of these models in practical situations are: (i) suitability for SES problems was cited as a benefit in 18 of the 21 studies (~86% of the papers); (ii) learning about the problem appeared in 16 of the 21 studies (~76% of the papers); (iii) engagement, which includes promotion of dialogue, the involvement of interested parties, sense of

ownership, and commitment, was cited in 13 studies (~62%); and (iv) transparency in 6 papers (í29%). Table 3 presents the studies in which each benefit was cited as a consequence of using the PSM-based model, and Figure 10 shows the percentage of papers in which these benefits were found.

Table 3: Benefits of the models

Benefits	Reviewed papers
Suitability for SES problems	Alexander et al., 2015; Baldwin et al., 2016; Dolbeth et al., 2016; Giordano et al., 2017; Gomes et al., 2018; Gregory et al., 2013; López et al., 2019; T. T. N. Nguyen et al., 2019; Pereira & Morais, 2020; Potts et al., 2015; Sani et al., 2019; Santoro et al., 2019; Santos et al., 2019; Schramm & Schramm, 2018; Slotte & Hämäläinen, 2015; Suriya & Mudgal, 2013; Watkin et al., 2012; Zare et al., 2019
Learning about the problem	Alexander et al., 2015; Baldwin et al., 2016; Giordano et al., 2017; Gomes et al., 2018; Hart & Paucar-Caceres, 2014; Hosseini & Rezaei, 2013; López et al., 2019; T. T. N. Nguyen et al., 2019; Pereira & Morais, 2020; Potts et al., 2015; Schramm & Schramm, 2018; Slotte & Hämäläinen, 2015; Suriya & Mudgal, 2013; Unalan, 2013; Watkin et al., 2012; Zare et al., 2019
Engagement	Baldwin et al., 2016; Dolbeth et al., 2016; Giordano et al., 2017; Gomes et al., 2018; Hart & Paucar-Caceres, 2014; Hosseini & Rezaei, 2013; López et al., 2019; Santoro et al., 2019; Santos et al., 2019; Schramm & Schramm, 2018; Slotte & Hämäläinen, 2015; Suriya & Mudgal, 2013; Unalan, 2013
Transparency	Baldwin et al., 2016; Dolbeth et al., 2016; Pereira & Morais, 2020; Potts et al., 2015; Schramm & Schramm, 2018; Slotte & Hämäläinen, 2015

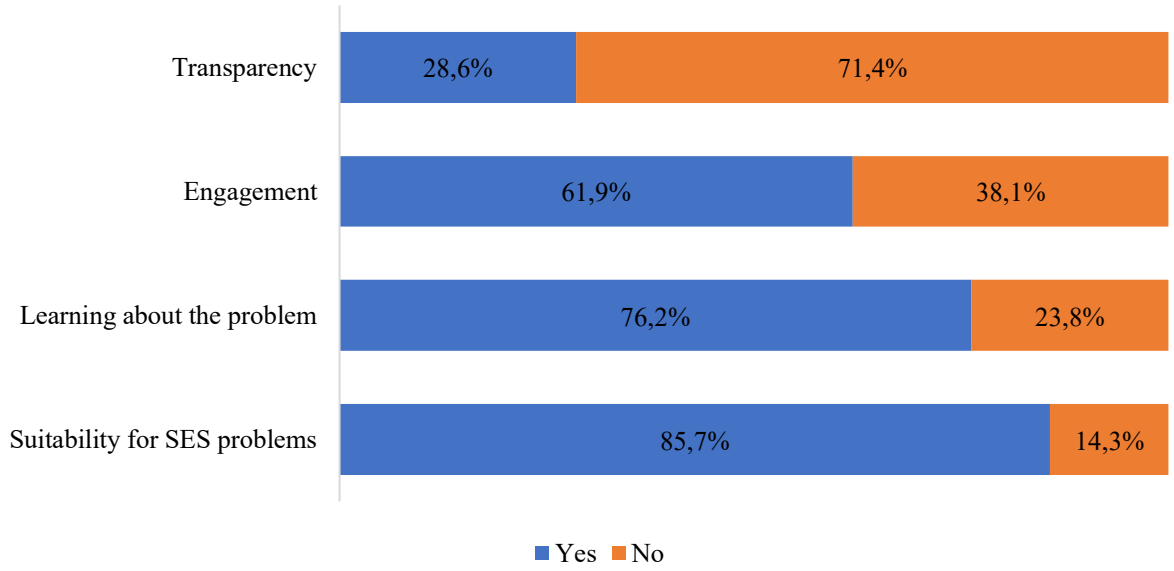

Figure 10: Benefits of the models

Regarding limitations, in almost half of the papers, authors did not discuss limitations of the models: Alexander et al. 2015; Dolbeth et al. 2016; Gregory et al. 2013; Hosseini & Rezaei 2013; Pereira & Morais 2020; Potts et al. 2015; Sani et al. 2019; Slotte & Hämäläinen 2015; Unalan 2013; Zare et al. 2019.

In the remaining papers, the limitations cited were: (i) time (5 studies in which there were discussions about limitations; ~45%); (ii) lack of quantitative analysis (3; ~27%) ; (iii) complexity of the method (3; ~27%); (iv) when to finish discussions and decide actions; (v) absence of interested parties; (vi) little analytical value, (vii) uncertainties in the outcomes; (viii) limitation of collective learning and implementation of actions, (ix) lack a deeper understanding. Table 4 presents the limitations identified in the reviewed papers.

Table 4: Limitations of the models

Limitations	Reviewed papers
Time	Gomes et al., 2018; López et al., 2019; Santoro et al., 2019; Santos et al., 2019; Suriya & Mudgal, 2013
Lack of quantitative analysis	Hart & Paucar-Caceres, 2014; Santoro et al., 2019; Watkin et al., 2012
Complexity of the method	Baldwin et al., 2016; Giordano et al., 2017; Schramm & Schramm, 2018
When to finish discussions and decide actions	Hart & Paucar-Caceres, 2014
Absence of interested parties	López et al., 2019; Suriya & Mudgal, 2013
Little analytical value	Gomes et al., 2018
Uncertainties in the outcomes	T. T. N. Nguyen et al., 2019
Limitation of collective learning and implementation of actions	Watkin et al., 2012
Lack a deeper understanding	Santos et al., 2019

In order to provides an overview of the reviewed papers, Table 5 summarizes the analysis made in this literature review.

Table 5: Summary of the reviewed papers

ID	Paper	Overview of the cases			Characteristics of PSM-based models				Results	
		Geographical location	PSMs used	Application context	Input gathering	Types of participants	Inputs	Outputs	Benefits	Limitations
1	Watkin et al. (2012)	Europe: United Kingdom	SSM	Hydrographic basins or groundwater	Interviews	Government, Private sector, and Specialists	Actors perception	Conceptual models, illustrations, and frameworks	Suitability for SES problems, and learning about the problem	Lack of quantitative analysis; and limitation of collective learning and implementation of actions
2	Gregory et al. (2013)	Europe: United Kingdom	DPSIR	Marine or coastal ecosystems	Other	Specialists	Actors perception	Conceptual model	Suitability for SES problems	Unidentified practical limitations
3	Suriya & Mudgal (2013)	Asia: India	SSM	Flood management	Workshops	Government, and Specialists	Actors perception	Conceptual models, illustrations, and frameworks	Suitability for SES problems; Learning about the problem; Engagement	Time and absence of interested parties
4	Unalan (2013)	Asian and Europe: Turkey	SSM	Hydrographic basins or groundwater	Interview and document analysis	Government, Private sector, Civil society, and Specialists	Actors perception and documents	Conceptual models, illustrations, and frameworks	Learning about the problem; and Engagement	Unidentified practical limitations
5	Hosseini & Rezaei (2013)	Asia: Iran	SSM	Hydrographic basins or groundwater	Interviews	Civil society and Specialists	Actors perception	Conceptual models, illustrations, and frameworks	Learning about the problem; and Engagement	Unidentified practical limitations
6	Hart & Paucar-Caceres (2014)	South America: Peru	SSM	Hydrographic basins or groundwater	Workshops	Government, Private sector, Civil society, and Specialists	Actors perception	Illustration and framework	Learning about the problem; and Engagement	Lack of quantitative analysis, and when to finish discussions and decide actions
7	Slotte & Hämäläinen (2015)	Europe: Finland	DSD	Management of lakes or lagoons	Workshop, observation, open discussion, and document analysis	Government, Private sector, and Civil society	Actors perception and documents	Framework	Suitability for SES problems; Learning about the problem; Engagement; and transparency	Unidentified practical limitations

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Table 5: Summary of the reviewed papers. Continued from previous page

ID	Paper	Overview of the cases			Characteristics of PSM-based models				Results	
		Geographical location	PSMs used	Application context	Input gathering	Types of participants	Inputs	Outputs	Benefits	Limitations
8	Potts et al. (2015)	Europe: European seas	SSM	Marine or coastal ecosystems	Workshops	Specialists	Actors perception	Conceptual models, illustrations, and frameworks	Suitability for SES problems; Learning about the problem; and Transparency	Unidentified practical limitations
9	Alexander et al. (2015)	Europe: Northeast Atlantic	SSM	Marine or coastal ecosystems	Workshops	Specialists	Actors perception	Conceptual models and frameworks	Suitability for SES problems; and Learning about the problem	Unidentified practical limitations
10	Baldwin et al. (2016)	Asia: Thailand and Cambodia	DPSIR	Marine or coastal ecosystems	Workshops	Government, Private sector, Civil society, and Specialists	Actors perception	Conceptual model	Suitability for SES problems; Learning about the problem; Engagement; and Transparency	Complexity of the method
11	Dolbeth et al. (2016)	Europe: Portugal, Spain, Ukraine, Poland, and Russia	DPSIR	Management of lakes or lagoons	Focus groups and citizen juries	Government, Private sector, and Civil society	Actors perception	Conceptual models and frameworks	Suitability for SES problems; Engagement; and Transparency	Unidentified practical limitations
12	Giordano et al. (2017)	Europe: Spain	FCM	Flood management	Workshop and interview	Government and Civil society	Actors perception	Cognitive maps and frameworks	Suitability for SES problems; Learning about the problem; and Engagement	Complexity of the method
13	Gomes et al. (2018)	Asia: Bangladesh	COA	Hydrographic basins or groundwater	Workshop, interview, open discussion, field investigation, and focus group	Government and Civil society	Actors perception	Conceptual models and frameworks	Suitability for SES problems; Learning about the problem; Engagement	Time and little analytical value
14	Schramm & Schramm (2018)	South America: Brazil	SODA	Hydrographic basins or groundwater	Workshop, interview, and observation	Government, Private sector, and Civil society	Actors perception	Cognitive maps and frameworks	Suitability for SES problem, Learning about the problem; Engagement; and Transparency	Complexity of the method

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Table 5: Summary of the reviewed papers. Continued from previous page

ID	Paper	Overview of the cases			Characteristics of PSM-based models				Results	
		Geographical location	PSMs used	Application context	Input gathering	Types of participants	Inputs	Outputs	Benefits	Limitations
15	Santos et al. (2019)	South America: Brazil	SODA	Forest management	Interviews	Government and Specialists	Actors perception	Cognitive maps	Suitability for SES problems; and Engagement	Time and lack a deeper understanding
16	Zare et al. (2019)	Asia: Iran	DPSIR	Hydrographic basins or groundwater	Interview, observation, field investigation, and document analysis	Civil society and specialists	Actors perception and documents	Conceptual models and frameworks	Suitability for SES problems; and Learning about the problem	Unidentified practical limitations
17	T. T. N. Nguyen et al. (2019)	North America: USA	SSM	Ecological restoration of animals	Observation	Government, Civil society, and Specialists	Actors perception	Conceptual models, illustrations, and frameworks	Suitability for SES problems; and Learning about the problem	Uncertainties in the outcomes
18	López et al. (2019)	South America: Colombia	SSM	Hydrographic basins or groundwater	Interview, workshop, survey, and field investigation	Civil society	Actors perception	Conceptual models, illustrations, and frameworks	Suitability for SES problems; Learning about the problem; and Engagement	Time and absence of interested parties
19	Santoro et al. (2019)	Europe: Slovenia	FCM	Flood management	Workshop and interview	Government, Civil society, and Specialists	Actors perception	Cognitive maps and frameworks	Suitability for SES problems; and Engagement	Time and lack of quantitative analysis
20	Sani et al. (2019)	Asia: Indonesia	SSM	Hydrographic basins or groundwater	Interview, focus group, and document analysis	Government, Civil society, and Specialists	Actors perception and documents	Conceptual model	Suitability for SES problems	Unidentified Practical limitations
21	(Pereira & Morais 2020)	South America: Brazil	SODA	Hydrographic basins or groundwater	Workshop, interview, and Document analysis	Private sector	Actors perception and documents	Cognitive maps and frameworks	Suitability for SES problems, Learning about the problem; and Transparency	Unidentified practical limitations

In the next section, a discussion on analysis made in this review is show

4 Discussion

In the reviewed models, almost 50% are based on the PSM-SSM. This PSM is a learning system and it was applied aiming to achieve a holistic understanding of the problematic situation. It is the most frequently used PSM in general and the same was observed in our review. Regarding the methodological aspects, SSM is quite simple and flexible and a consequence of this is that each application may be different from each other, making difficult the replication of the research. Maybe for this reason, in almost 50% of the reviewed models, in which SSM was applied, it was combined with other techniques. In our opinion, SSM is not a method, but a type of methodology that provides the basic steps and tools for structuring complex problems (see considerations on differences between methods and methodologies in Howick & Ackermann, 2011). In this sense, the combination of it with other methods/techniques should be encouraged in order to build multimethodologies.

The second most frequently used PSM in the context of SES is the DPSIR. It was created by the European Environment Agency - EEA (1999) and it is widely used to build environmental indicators. Although it is debated whether DPSIR is a PSM, this discussion is not restricted to this method (see Smith & Shaw, 2019). We considered it a PSM, since it is applied in a participatory and systemic way (Bell, 2012), and given the evidence from the reviewed studies in this paper. FCM was applied in two studies as a PSM, however, despite this method has a wide range of applications and seems to be very suitable for structuring of complex problems, it does not appear in the traditional literature on PSMs. We reviewed only two examples, but in the literature various other techniques are being successfully applied for structuring complex problems, despite they are not considered as PSMs by the Soft-Operational Research community. There is no application using SCA, which composes with the SSM and SODA the group of the best known PSMs.

Regarding application contexts, most of them are related to hydrographic basins or groundwater management, whose problems are complex in nature, that is, involve multiple actors, with different perspectives, conflict of interests, and a high level of uncertainties regarding solutions to mitigate the problems.

We noted that participatory processes, with a heterogeneous group, including specialists and ordinary participants, make the structuring of the problem richer. However, it is important to ensure effective participation of all, avoiding that local community representatives are not marginalized in these interventions. In this sense, the facilitation PSM-based models should provide mechanisms for dealing with this aspect. The PSM-based models used the perception

of these interested parties and some supplementary documents, which were used: to obtain a preliminary view of the problematic situations, to compare the documented information with the information obtained from them, and to formulate decision alternatives for solving the problem at hand.

Workshops and interviews were the techniques most used in the reviewed papers to model the perceptions of interested parties, which most often form heterogeneous groups, with different backgrounds. These participative techniques allow to obtain important sources of knowledge about problematic situations. However, some caveats must be made. Watkin et al. (2012) make some alerts about conducting only interviews, this technique can limit collective learning and implementation of agreed changes. They make this alert when using SSM, but it is believed that this can be considered when using other PSMs, given the importance of building a common understanding of problematic situations.

Therefore, we understood that techniques such as workshops or other collective approaches may be more appropriate. Despite recognizing the difficulties of bringing different interested parties together, usually more than once. Therefore, it is suggested the development and use of information and communication technology tools, such online meetings, in problem structuring. The PSMs-based models the input information using diagrammatic structures, which are a simplified representation of the different perspectives that are used to create a holistic understanding about the problematic situation. Several types of diagrams were used in the reviewed models and most of them use more than one type.

Learning about the problems or engagement were cited in approximately 90% of the reviewed papers as results achieved with the use of the models. This finding corroborates with what is already discussed in the literature regarding the strengths of PSMs (see Khadka et al., 2013; Rosenhead, 2006; Rouwette et al., 2009). Another important benefit is transparency, which is a desirable characteristic of decision-making process whose consequences will have an impact on those involved and on third parties. Suitability of the PSM for dealing with SES problems was another benefit cited by the studies.

Time consumption and the lack of quantitative data seems to be the main limitations on the use of the models. As for the PSMs, lack of methodological rigor and consequent subjectivity is a concern. To address this subjectivity, the use of systems dynamic modeling approaches is encouraged. Regarding the PSM-based models that use cognitive mapping, the authors pointed out the difficulty in construct and validate these maps with the group.

5 Conclusion

This paper provides a literature review on the use of PSMs in SES. Our review encompasses studies that have been published in peer-reviewed journals over the last decade. We identified 21 papers that present PSM-based models used in SES. The analysis of these papers was performed considering three dimensions of analysis: (i) overview, which includes the geographical location where these researches have been developed, type of PSM used, and application context; (ii) characteristics of the models, which aim to identify the approaches used for collecting input data, types of participants, inputs, and outputs of the models; and (iii) the results dimension to analyze the main benefits and limitations of the models.

Most of the studies were developed in Europe and Asia; SSM is the most frequently applied PSM and the use of multimethodologies is a tendency. The application areas are intricately linked to the management of water resources. Commonly, interviews and workshops are held to model the perceptions of interested parties, which are used as input information for the models, in which outputs are different types of diagrammatic structures. The main benefits identified were sustainability for SES problems, learning, engagement, and transparency. And the most prominent limitations were time, the lack of quantitative data, and the complexity of some methods, the latter limitation particularly associated with PSMs that are based on cognitive mapping. We concluded that PSMs are very suitable for dealing with the inherent complexity of the SES. However, these use of PSMs in this context is still small and should be encouraged.

Our review has some limitations: only one database was used, and the analysis carried out based on subjective reasoning and end up suffering interferences from the authors' biases, but we considered that this has been softened with the creation of criteria and protocols.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES).

References

Observation: The list of references is at the end of this document.

CHAPTER 4

THIRD PAPER

Facilitation Model Based on SSM for Supporting Brazilian Watershed Committees

Facilitation Model Based on SSM for Supporting Brazilian Watershed Committees[3]

Abstract

In Brazil, watershed committees are responsible for operationalizing the participatory and decentralized management of water resources provided for in the country's legislation. They are permanent deliberative, advisory, and propositional bodies composed of representatives of governments, water resources users, and civil society. Therefore, the decision-making process in these committees inevitably involves multiple actors with different points of view, values, powers, goals, and conflicting interests. Thus, complex problematic situations emerge, as conflicts. Formal approaches to support participatory decision-making processes that occur in Brazilian watershed committees is necessary and urgent. Problem Structuring Methods are qualitative approaches developed to lead with complex problematic situations. Specifically, Soft Systems Methodology (SSM) is the most used and know Problem Structuring Method and has been used successfully to structure complex problematic situations in Social-ecological systems, such as those faced in committees. Therefore, this paper proposes a facilitation model based on Soft Systems Methodology (SSM) for supporting decision-making processes in Brazilian watershed committees. Additionally, the facilitation model was used to structure an environmental conflict that exists in an area of the watershed of the Paraiba do Norte River. The main advantages of the proposed facilitation model are (i) learning about a complex problematic situation; (ii) the formalization of a process to help the decision-making about a complex problematic situation; (iii) the assignment of roles and responsibilities to actors; (iv) the availability of a set of tools that facilitate the structuring of complex problematic situations; and (v) flexibility, it can adapt to the needs of the committees.

Keywords: Problem Structuring Methods (PSM). Soft Systems Methodology (SSM). Environmental conflicts. Social-Ecological systems. Watershed committees.

1 Introduction

In Brazil, water resources management is regulated by the Federal Law No. 9.433/97, which instituted the National Water Resources Policy and created the National Water Resources Management System. This legal framework establishes that water resources management must be decentralized and include the participation of public authorities, water users, and representatives of civil society. Thus, each watershed is managed by a committee, which is a deliberative, propositional, and consultative body comprised of 40% of water resources users (industrial, agro-industrial, etc.), 40% of government representatives, and 20% from civil society. The role of these committees includes to promote debates on issues related to water resources, to arbitrate conflicts related to water resources, to approve and monitor the execution

[3] Authorship: Alexandre de Araújo Gomes Júnior; Vanessa Batista Schramm & Fernando Schramm, submitted to European Journal of Operational Research (EJOR) (Qualis CAPES: A1) on January 18, 2021.

of a management plan for the watershed, to establish mechanisms for charging water resources, to determine criteria, and promote the apportionment of construction cost in the watershed (Brasil, 1997).

Each watershed committee integrates various interest groups, with different values, powers, points of view, and goals, to deliberate over issues, the consequences of which will have a great impact on those involved, on third parties, and on the environment. According to Dao et al. (2019), when individuals are faced with this type of situation, conflicts emerge. Indeed, as observed by Medeiros et al. (2017) and Schramm & Schramm (2018) conflicts (declared or not) are common in the decision-making processes that occur in watershed committees. Moreover, the nature of the decision that is made in these committees involves uncertainties. Therefore, the watershed committees make decisions about complex Social-Ecological Systems.

According to Perkins (2011), the success of these participatory decision-making processes depends on how they are carried out. Silva et al. (2010) add that the water resources management with the involvement of diverse actors can be complex, can be complex, can generate conflicts, and more powerful actors can influence the preference of others. Therefore, a formal approach for supporting participatory decision-making processes that occur in Brazilian watershed committees is necessary and urgent.

PSMs are a class of qualitative approaches (methodologies, methods, and tools) of a participatory and interactive character, whose objective is to assist in the structuring of complex problems (Rosenhead, 1996), aiming to generate agreements that could or would be implemented in situations where there are no evident agreements about the problem and its solution (Ackermann, 2012). PSMs stems from the need to understand a wide range of issues where there is no consensus (Rosenhead, 2006). Ackermann (2012) adds that PSMs are very focused on the need to meet the political and analytical demands of group decision-making. Rosenhead & Mingers (2001) present some characteristics of PSMs: non-optimizing; simplicity and transparency, aimed at clarifying the terms of conflict; reduce data demands; conceptualizes people as active subjects; facilitates planning from the bottom-up; accepts uncertainty, and aims to keep options open.

PSMs have been successfully applied in the context of social-ecological systems: management of hydrographic basins or groundwater (Gomes et al., 2018; Hart & Paucar-Caceres, 2014; Hosseini & Rezaei, 2013; López et al., 2019; Pereira & Morais, 2020; Sani et

al., 2019; Schramm & Schramm, 2018; Unalan, 2013; Watkin et al., 2012; Zare et al., 2019); marine or coastal ecosystems management (Alexander et al., 2015; Baldwin et al., 2016; Gregory et al., 2013; Potts et al., 2015); flood management (Giordano et al., 2017; Santoro et al., 2019; Suriya & Mudgal, 2013); management of lakes or lagoons (Dolbeth et al., 2016; Slotte & Hämäläinen, 2015); ecological restoration of animals (T. T. N. Nguyen et al., 2019); and forest management (Santos et al., 2019). In a literature review on PSMs performed by (Gomes Júnior, 2021), the author verified that PSMs have been applied in different areas and the Soft Systems Methodology (SSM) is the most frequently applied: ~87% of the studies that applied PSMs in the context of the healthcare sector used the SSM; for business management, 66% of the cases are based on SSM; and for environmental management, ~41% of the cases applied SSM. Regarding, the studies cited above, around half of the cases are based on SSM.

SSM (Checkland, 2001) is a learning system about complex problematic situations that aims to find accommodations and take actions to improve these situations. This methodology assumes that different actors make different evaluations about the real-world (ever-changing interacting flux of events and ideas) and systems logic is helpful to lead with real-world situations, which usually complex. SSM uses models to structure debates in which conflicting objectives, needs, purposes, interests, values of the actors can be extracted and discussed (Checkland, 2001). Traditionally, SSM consists of a seven-stages process: actors finding out about a problem situation in the real-world and express it (stages 1 and 2); to construct systemic models of purposeful activity, according to their perspectives (stages 3 and 4); to compare these models with the existing real-world situation (stage 5); to identify changes that are culturally feasible and systemically desirable (stage 6); and to take action for improving the problem situation (stage 7) (Checkland, 2001).

The following benefits were observed in the studies that applied SSM in social-ecological systems: suitability for social-ecological problems (Alexander et al., 2015; López et al., 2019; T. T. N. Nguyen et al., 2019; Potts et al., 2015; Sani et al., 2019; Suriya & Mudgal, 2013; Watkin et al., 2012); learning about the problem (Alexander et al., 2015; Hart & Paucar-Caceres, 2014; Hosseini & Rezaei, 2013; López et al., 2019; T. T. N. Nguyen et al., 2019; Potts et al., 2015; Suriya & Mudgal, 2013; Unalan, 2013) engagement of the actors; (Hart & Paucar-Caceres, 2014; López et al., 2019; Suriya & Mudgal, 2013; Unalan, 2013) and transparency (Potts et al., 2015). The limitations cited are: time needed for facilitation (López et al., 2019; Suriya & Mudgal, 2013); lack of quantitative analysis (Hart & Paucar-Caceres, 2014; Watkin et al., 2012); when to finish discussions and decide actions(Hart & Paucar-Caceres, 2014);

absence of interested parties (López et al., 2019; Suriya & Mudgal, 2013); and uncertainties in the outcomes (T. T. N. Nguyen et al., 2019).

In this paper, we applied the SSM foundations to construct a facilitation model for supporting decision-making processes that occur in Brazilian watershed committees. The paper is structured as follows: Section 2 presents the foundations of SSM and a review on the use of SSM in the context of social-ecological systems; Section 3 presents the proposed model; Section 4 presents an application of the model; Section 5 presents the discussions; and Section 6 shows conclusions, limitations, and suggestions for future work.

2 SSM and its applications

SSM is an organized learning system that aims to achieve an understanding of a problematic situation in order to propose actions for solving it. SSM deals with “what to do” and “how to do it” as being part of the problem (Checkland, 2001). For this, a seven-stage process was proposed (Figure 1).

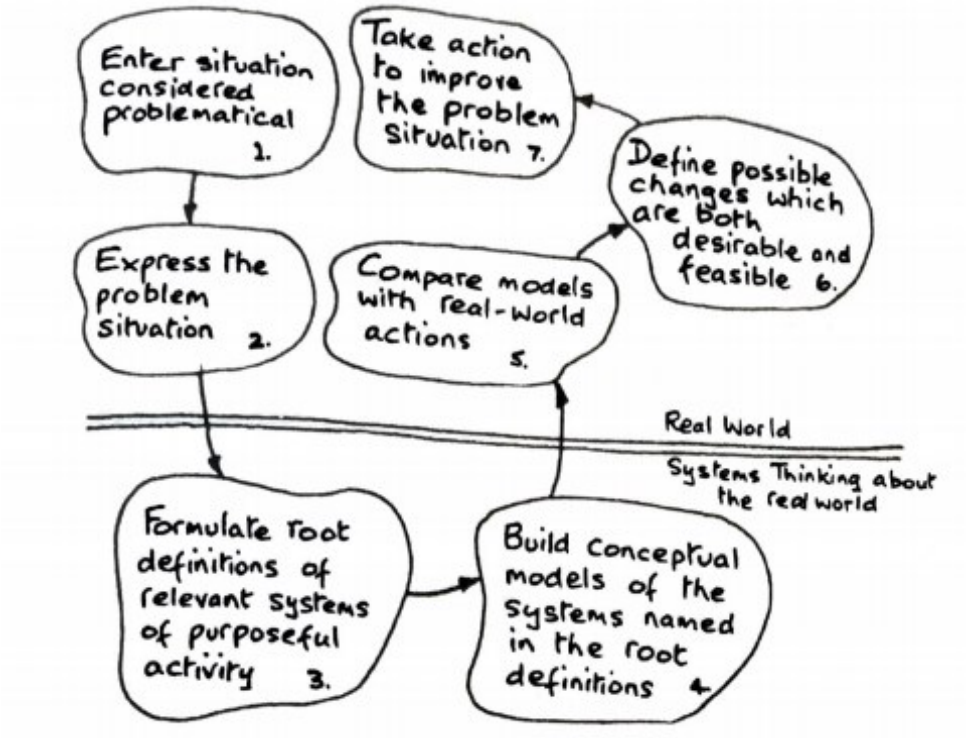


Figure 1: SSM process. Source: Checkland, (2001)

SSM starts by trying to find out a problematic situation, which includes investigate and understand social, cultural, and political aspects of the situation, and represent it in a diagram traditionally called "rich picture" (Stages 1 and 2). In stage 3, the system thinking starts with the formulation of the “root definitions”, which represent systems that describes desirable

transformations that are relevant to exploring the situation and should be produced using the CATWOE mnemonic (Customers, Actors, Transformation, World view, Owner, and Environment). In stage 4, the "root definitions" will be modeled as conceptual models, which express the activities necessary to transform the situation and mechanisms for monitoring and control. Then, the conceptual models are compared with the real world to generate discussions (Stage 5) whose goal is to identify feasible and desirable changes to improve the problematic situation (Stage 6). Finally, with the implementation of these changes (Stage 7), the SSM cycle ends.

2.1 SSM in practice

SSM has been applied in different areas, such as business management, environmental management, healthcare sector, social issues, and other areas. Specifically, SSM has been successfully applied in social-ecological systems, which are integrate people and nature (Cumming, 2014). Some examples of these applications are depicted below.

Watkin et al. (2012) applied SSM to investigate the challenges for small-scale hydropower development from the perception of the involved actors, in the UK. For this, the authors conducted interviews with representatives of government, the private sector, and specialists to gather the data necessary for structuring the problem. According to the authors, SSM allowed enhancing the better understanding of the role of the stakeholder and the problem. Among limitations, the authors pointed out the limitation of collective learning and implementation of actions and lack of quantitative analysis.

Suriya & Mudgal (2013) used SSM with two other tools Analytic Hierarchy Process (AHP), and Force Field Analysis to understand and solve problems due to flooding, in India. For this, the authors performed workshops with representatives of government and specialists. According to the authors, SSM is suitable for exploring problems related to floods, allows the actors involved to learn about the problem, and enables the engagement of these actors. Among limitations, they cited: time-consuming of the intervention and absence of actors.

Unalan (2013) applied SSM to investigate possible Environmental Based Management implementation in a hydrographic basin, in Turkey. To achieve your goals, the author conducts interviews with representatives of government, the private sector, civil society, and specialists, and analyses documentation about the situation. The benefits of using SSM in the study were: learning about the problem, and engagement of the actors.

Hosseini & Rezaei (2013) presented a case study in which SSM was used with Unified Modeling Language (UML) for the development of an information system for sustainable natural resource management in a watershed in Iran. UML was utilized because conceptual models of SSM was not enough to design the information system. To this, the authors performed interviews with farmers and specialists. According to the authors, SSM is an appropriate method for participatory decision-making, and it can address the actors' problems and concerns.

Hart & Paucar-Caceres (2014) applied SSM to debate the environmental impact of mining operations in Peru. For this, workshops were conducted with representatives of government, private sector, civil society, and specialists involved in the complex situation. According to the authors, the intervention allowed actors to engage and to learn about the problem. In this case, the main goal was not to find solutions but was to establish communication between the actors involved. When to end the debate and begin the selection of the actions was the main limitation cited by the authors.

Potts et al., (2015) showed three cases studies in which SSM was applied to identify psychological, political, institutional, social, or cultural obstacles of social-ecological systems in the European seas. For this, workshops with specialists were held. The authors consider that transparency, learning about the problem, and suitability to problems in social-ecological systems are the main benefits of using SSM.

Alexander et al. (2015) used SSM with Driver–Pressure–State–Welfare–Response (DPSWR) to analyze the complexity of social and ecological phenomena that influence sustainable exploitation of a marine ecosystem in the Northeast Atlantic. Workshops with specialists were conducted. Adequacy to the problem and learning about the problem were benefits of using multimethodology.

T. T. N. Nguyen et al. (2019) presented a case study in which SSM was used to structure a situation of ecological restoration from the perception of the actors involved, in the USA. The authors identified the current situation, showed the involved actors and their relationships, and developed actions for change. For this, they observed and recorded information in meetings with representatives of government, civil society, and specialists. The authors consider that the SSM allowed learning about the problem and that it is suitable for the type of problem analyzed, but they consider that the outcomes may have a high level of uncertainties.

López et al. (2019) applied SSM with the tool socio-technical networks to design technical solutions that lead to sustainable development and active community engagement in a water resource conservation project in Colombia. For this, the authors conducted interviews, workshops, and a survey with representatives of civil society, and performed field investigation. According to them, the use of the SSM allowed to understand the problem, to promote the engagement of the actors. They also concluded the SSM is suitable for the type of situation analyzed, but the consumption of time and the absence of actors were limitations of the intervention.

Sani et al. (2019) used SSM to develop a collaborative governance system to manage and restore a watershed ecosystem in Indonesia. For this, the authors conducted interviews, focus groups with representatives of government, civil society, and specialists; and analyzed documents related to the case.

3 Proposed facilitation model

The proposed participatory decision-making model for Brazilian watershed committees is a facilitation model. In this type of model, the definition of the problem, creation and analysis of the models, and provision of recommendations are made interactively with the actors involved in the problem and the facilitator (Franco & Montibeller, 2010). According to these authors, for facilitation models, four assumptions are required: (1) problems are social constructions; (2) subjectivity is inescapable; (3) actors want satisficing solutions, instead of optimal ones; (4) involvement of the actors increases commitment for implementation.

3.1 Actors and roles

The proposed model uses the organizational structure of the Brazilian watershed committees. All actors of the facilitation model must be members of the committee and they are classified into two groups: (i) facilitation group, which is responsible for conducting the logistics and operation of the facilitation process, and (ii) working group, which is responsible for the analysis of the complex problematic situation before its submission to the plenary of the committee.

The facilitation group is a permanent group, and it is composed of members of the executive secretary of the committee, who will perform the role of facilitator and recorder, both responsible for conducting the process. The facilitator role is multifaceted: information seeker, a guiding force, a clarifier, a consolidator of opinions, a peacekeeper, a motivator, and a technical advisor with respect to the technical aspects of the model (Tako & Kotiadis, 2015).

Some key skills are desired from the facilitator: active listening, chart writing, managing group dynamics and power shifts, and reaching closure (Franco & Montibeller, 2010). The recorder will assist the facilitator, observing the situation and taking notes (Tako & Kotiadis, 2015).

The working group is a temporary group that is created by the committee aiming to structure a complex problematic situation and it should be extinguished after a deliberation of the committee regarding the problem. The members of the working group are the "clients" of the facilitation and they should discuss the problematic situation in order to construct a holistic understanding of the situation, before submitting it for the appreciation of the plenary of the committee. The working group is composed of members of the committee, respecting the proportionality adopted in the formation of the committees: government (40%), water resources users (40%), and civil society (20%). The diversity of the group contributes to innovation and creativity in the analysis of the problem (Grinyer, 2000). The effectiveness of the facilitation decreases when the size of the group increases (Papamichail et al., 2007). In our model, we will follow the recommendation presented in the study by Phillips & Phillips, (1993) who suggest groups of 7 to 15 people. Among these members, three key decision-makers are selected (one for each segment) to represent the interests of his/her respective segment in the facilitation process. Table 1 presents the actors and roles of the facilitation model.

Table 1: Actors and roles of the facilitation model

Group	Description	Composition	
		Name	Quantity
Facilitation group	A permanent group composed by members of the executive secretary of the committee. This group is responsible for conducting the logistics and operation of the facilitation process.	Facilitator	1
		Recorder	1
Working group	The working group is a temporary group that is created by the committee aiming to structure a complex problematic situation.	Discussion group	7-15
		Key decision-makers	3

3.2. Facilitation process

3.2.1. First Phase: Pre-Structuring the complex problematic situation

The facilitation process starts with the identification of a complex problematic situation that is being addressed by the committee. For this, the facilitator should identify a topic, whose discussions during the plenary of the committee have the following characteristics: divergent points of view and conflicting interests among the members of the committee, absence of alternatives for mitigating the problem, and/or high level of uncertainties regarding these

alternatives. If a complex problematic situation is identified, then, the executive secretary of the committee will establish a working group for discussing and understating the problem in order to structure it in terms of alternatives for mitigating the problem. After that, the members of this group will choose the key decision-makers. Then, the facilitation group will organize the logistics necessary to perform the structuring of the complex problematic situation.

Finally, the analysis of the complex problematic situation starts for which the steps based on the SSM are applied: (i) construction of the rich picture; (ii) construction of the conceptual model; (iii) establishment of the alternatives for mitigating the complex problematic situation. At the end, these alternatives are submitted for appreciation by the plenary of the committee.

The model addresses one complex problematic situation at a time. Figure 2 presents the flowchart of the model.

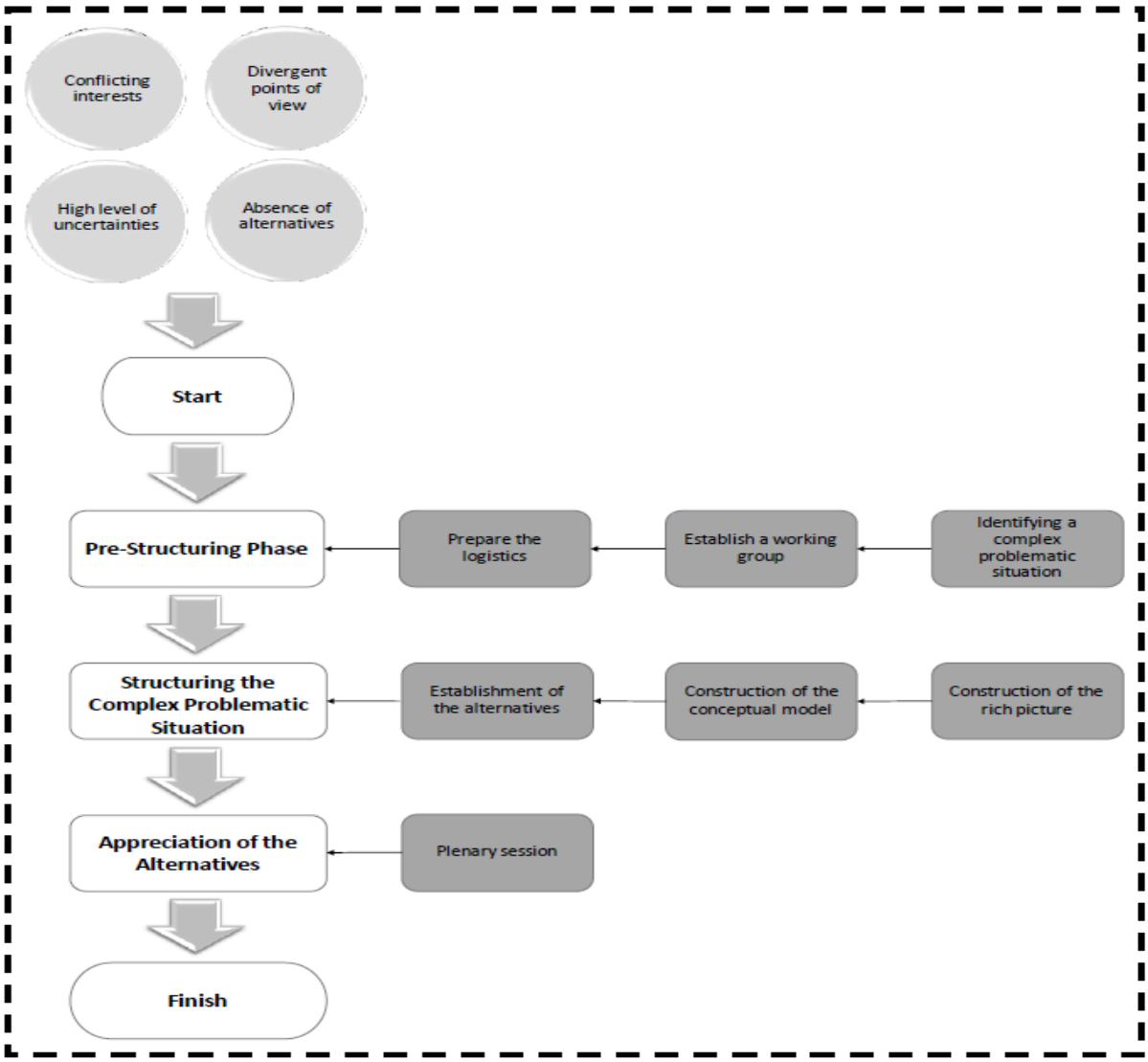


Figure 2: Flowchart of the proposed model

3.2.2. Second Phase: Structuring the complex problematic situation

The steps necessary for structuring the complex problematic situation are described below.

Step 1 - Construction of the rich picture

At this step, the working group is encouraged to explore the problematic situation from their perspectives and to express it through a graphical representation, named rich picture. For this, the facilitator should ask the questions used in the study by Bunch, (2003) to conduct a semi-structured discussion.

1. What is the problem?

2. Why is it a problem?

3. What would the problem look like if it were solved?

4. Whose problem is it?

5. Who owns it?

6. Where is it a problem?

7. Is it localized and isolated, or is it widespread and pervasive?

8. When is it a problem?

9. How long has it been a problem?

10. Really now, what is the problem? Go back to your statement in question 1 and determine whether: (a) the problem you defined is a symptom of a bigger problem, or (b) a solution to what you think is the problem. If you decide you are dealing with either symptoms or solutions, go back to question 1 and try to identify the real problem.

11. Finally, what would happen if nobody did anything to solve the problem?

This semi-structured discussion will be the input for the construction of the rich picture. The facilitator will perform the following steps:

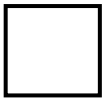
1. Identifying actors, root factors, middle factors, end factors, and points of view.

2. Establishing causes and effect relationships between the factors.

3. Building the graphical representation that summarizes the problematic situation with the information collected in the previous steps.

Table 2 presents theoretical and graphical elements of the rich picture.

Table 2: Graphical elements of the rich picture

Graphical element	Label	Description
	Actors	Indicates people and institutions involved in the problematic situation.
	Root factors	Indicates problems that are sources of problematic situations and causes or influences other problems.
	Middle factors	Indicates problems caused by root factors and that cause other problems. The middle factors can be affected by the problems that cause.
	End factors	Indicates problems caused by root factors or the middle factors, but they do not cause other problems. However, the end factors can affect middle factors.
	Viewpoints	Indicates opinions, value judgments and perceptions of the actors
	Cause-and-effect relationship	Indicates a cause-and-effect relationship between factors, in which one factor creates or contributes to aggravate another
	Boundary	Indicates the limits of a problematic situation

After that, the facilitator will invite the key decision-makers to validate the graphical representation. For this, the facilitator will promote a semi-structured discussion with these three actors. The following questions can be used for guiding the discussion:

1. Are there other actors involved in this problematic situation?
2. Are these actors involved?
3. Is this a root factor?
4. Is this a middle factor?
5. Is this an end effect?
6. Does this relationship exist?

During the validation, the key decision-makers can suggest slightly changes in the rich picture in order to achieve a more realistic representation of the problem according to the point of views of the three segments (government, users, and civil society). However, if huge changes are suggested, the rich picture should be updated by the working group (the process return to the previous activity).

Step 2 - Construction of the conceptual model

The goal of this step is to construct of the conceptual model. This step is comprised of two main activities: (i) development of the root definition; and (ii) construction of the conceptual model.

The facilitator will provoke a semi-structured discussion with the key decision-makers in order to determine the relevant system, to formulate the root definition, and to perform the CATWOE analysis. To facilitate this, we recommend that the facilitator follows the instructions described below:

1. Explain the basis of the root definitions and relevant systems.

2. Encourage the key decision makers to present the relevant system with SSM formula: A system that does P (what?) by Q (how?) to help to achieve R (Why?).

3. Develop the root definition of the relevant system.

4. Conduct the CATWOE analysis (Table 3) with the three decision-makers.

Table 3: CATWOE description

ID	Issue	Question?
C	Customer	Who are the victims or beneficiaries of the system?
A	Actors	Who would do the activities?
T	Transformation process	What is the purposeful activity expressed as input, transformation, output?
W	World view	What view if the world makes this definition meaningful?
O	Owner	Who could be stop this system?
E	Environmental constraints	What constrains in its environment does this system take as given?

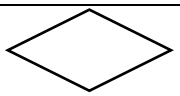
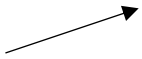
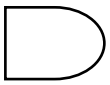
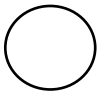
After the development of the root definition of the relevant system, the facilitator will construct the conceptual model of the relevant system. For this, we follow the recommendations presented in the study by (Checkland, 2001):

1. The conceptual models must describe actions that should exist in the relevant systems formulated in the root definitions.

2. To facilitate the understanding of the conceptual model, a model with 5 to 9 actions is recommended.
3. Criteria for effectiveness (is this the right thing to be doing?), efficacy (does the means work?) and efficiency (is there minimum use of resources?) for the conceptual models must be defined.
4. Conceptual models are comprised of an operational system and a monitoring and control system.

In our facilitation model, the conceptual model should be represented as a flowchart. The graphic elements and some instructions needed to build the flowchart are shown in Table 4.

Table 4: Graphic elements for building the conceptual model

Graphic element	Description	Questions to analyze the flowchart
	Indicates the beginning or the end of the process	-
	Indicates each activity that needs to be performed	Is this activity necessary? What is the value of this activity? Is it possible to improve, to make it simpler?
	Indicates a decision-making point (An assertion is tested. If true, the process goes one way, if false, the other).	Is this decision necessary? Is it well defined or subject to interpretation and errors?
	Indicates the direction of flow from one point or activity to another.	-
	Indicates the documents used in the process	Is this document necessary? Is this information unique or is it in duplicate?
	Indicates waiting. The approximate waiting time is shown inside the symbol	Is this waiting necessary? Can time be reduced? Isn't this a delay?
	Indicates that the flowchart continues from this point in another circle with the same letter or number, which appears inside it.	-

Source: Adapted from Peinado & Graeml, (2007).

After that, the facilitator will invite the key decision-makers to present the conceptual model, they can suggest changes and improvements that can be implemented with the facilitator's agreement.

Step 3- Establishment of the alternatives for mitigating the complex problematic situation

The aim of this step is to identify alternatives mitigating the problem. Firstly, the working group will compare the rich figure (real situation) with the conceptual model (ideal situation) in order to identify the main differences between both situations and then to suggest what can be done to move from the real to the ideal situation. To encourage a discussion among the members of the working group, the facilitator should ask the following questions to them:

1. Does this happen in the problematic situation? How?

2. Is this issue important to improve the problematic situation?

3. What could be done to improve the problematic situation?

4. Is this change desirable?

5. Is this change feasible?

We suggest that the list can be elaborate as the model presented in Table 5.

Table 5: List of possible changes to improve the problematic situation

Conceptual model	**Problematic situation**	**What are the differences?**	**Is this issue important**	**Possible actions for change**	**Is this change desirable?**	**Is this change feasible?**	**Actors responsible**
What the conceptual model presents.	What the problematic situation presents.	Describe de differences.	Yes or no	Describe possible actions for change	Yes or no	Yes or no	Actors responsible for the action

Then, the list elaborated by the working group will be reviewed by the key decision-makers who are allowed to add, delete, suggest and/or complement both desirable and feasible actions for mitigating the problem. The outcome of this step, is a list with both agreed desirable and feasible actions that accommodate the different point of views of the committee.

3.2.3 Third phase: Appreciation of the alternatives by the plenary

In Brazilian watershed committees, decisions are made in a transparent and democratic public way in plenary sessions. In the proposed facilitation model, the learning cycle ends with the appreciation of the alternatives, which were formulated in the previous phase, by the plenary of the committee that will discuss and decide about what actions to be implemented according to its own rules.

4 Application of the model

Because of the pandemic, the activities of watershed committees in Brazil were suspended, and it was not possible to apply the model with the members of committees acting as facilitator and working group, as it is recommended in the proposed model. However, to illustrate the application of the model, we applied the steps of phase 2 to structure an environmental conflict that exists in an area of the watershed of the Paraiba do Norte River, in Northeastern Brazil. Environmental conflicts are complex in nature and thus the proposed model can be applied in order to propose alternatives for solving the conflicts or at least minimizing their consequences. To ensure the diversity in the structuring of the problem, we consider the perspectives of the involved in the conflict, which was gathered in a previous study by Pessoa (2019), who performed a detailed description about the conflict considering the point of views of various stakeholders, which were collected from bibliographic sources, on-site visits, and interviews.

Firstly, we present a description of the study area that aims to generate a primary understanding of the conflict.

4.1 Study area

The study area is the Sumé Irrigated Perimeter (SIP), which is located on the Sucuru River, in the watershed of the Paraiba do Norte River, Northeastern Brazil (Figure 3). Irrigated perimeters are areas defined by the State for the implementation of public irrigated agriculture projects (Pontes et al., 2013). It is one of the initiatives of the Brazilian Federal Government to try to minimize the negative impacts due to long periods of drought in the region, whose predominant climate is characterized by low annual precipitation, high temperatures, and high evaporation. Thus, these irrigated areas are part of a public policy that aims at the development of the Northeast region of Brazil through increased competitiveness, increased production, and agricultural adaptation to irregular rainfall (Silveira et al., 2018). The main objective of these projects was to promote economic benefits to the regions where they had been installed. The SIP was established in the 1970s, and it extends along the Sucuru River for 12 km downstream the floodgate of the public reservoir of Sumé, which has a storage capacity of approximately 45 million m^3. At the installation of the SIP, an area of approximately 300 ha were projected to be irrigated, comprised into 51 agricultural lots, of which 47 were occupied by local farmers who cultivated in the area tomatoes, corn, beans, bananas, melons, and other fruits.

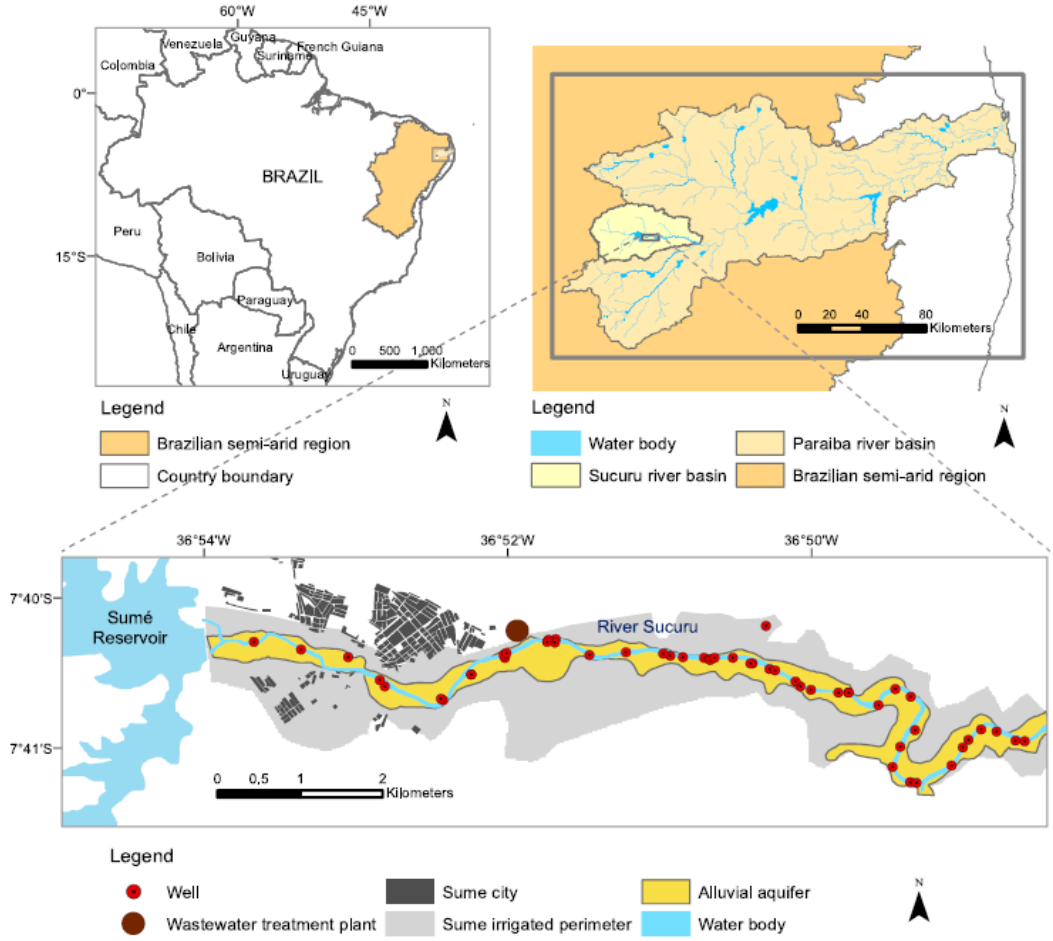


Figure 3: SIP. Source: Tsuyuguchi et al., (2020).

In the last years, the volume of the reservoir reached unsustainable levels due to a long period of drought in the region, the consequence of which was the partial interruption of the irrigation. The situation caused many of the farmers to abandon their lots, then part of the irrigation system was abandoned and degraded due to the lack of maintenance. Moreover, throughout the years, the flood irrigation model used by the farmers provoked the infertility of the soil in some parts of the SIP. In other lots, the soil was contaminated; according to the farmers, the contamination is due to the discharge of water from the city's sewage treatment, but the company responsible for water treatment and supply claims that the soil contamination is due to the disposal of waste of pesticides and fertilizers used in farming practices. Also, the banks are polluted, and the riparian forest is degraded. Currently, only 17 agricultural lots have been able to maintain irrigation, which means that the cultivated area varies from 8–43 ha (Tsuyuguchi et al., 2020). This situation has economic, social, and environmental impacts on those actors directly involved, as well as on the region a whole since the SIP is an important mechanism that aims to promote the sustainable development of the region.

4.1.1 Construction of the rich picture

The main actors in the conflict are: (i) the farmers, who want to reactivate the SIP, but without providing the financial resources that are necessary, neither a long term management plan for this; (ii) the Brazilian National Department of Works against Drought (DNOCS), which has the technical resources to reactivate the irrigated perimeter, but do not have the financial resources for implementing it; (iii) the Brazilian National Water Agency (ANA), which is responsible for the management of water resources in Brazil, including controlling the level of reservoirs; and (iv) the local water and sewage company in the state of Paraíba (CAGEPA), which is responsible for the city's supply and sewage treatment plant. Representatives of these segments will comprise the working group.

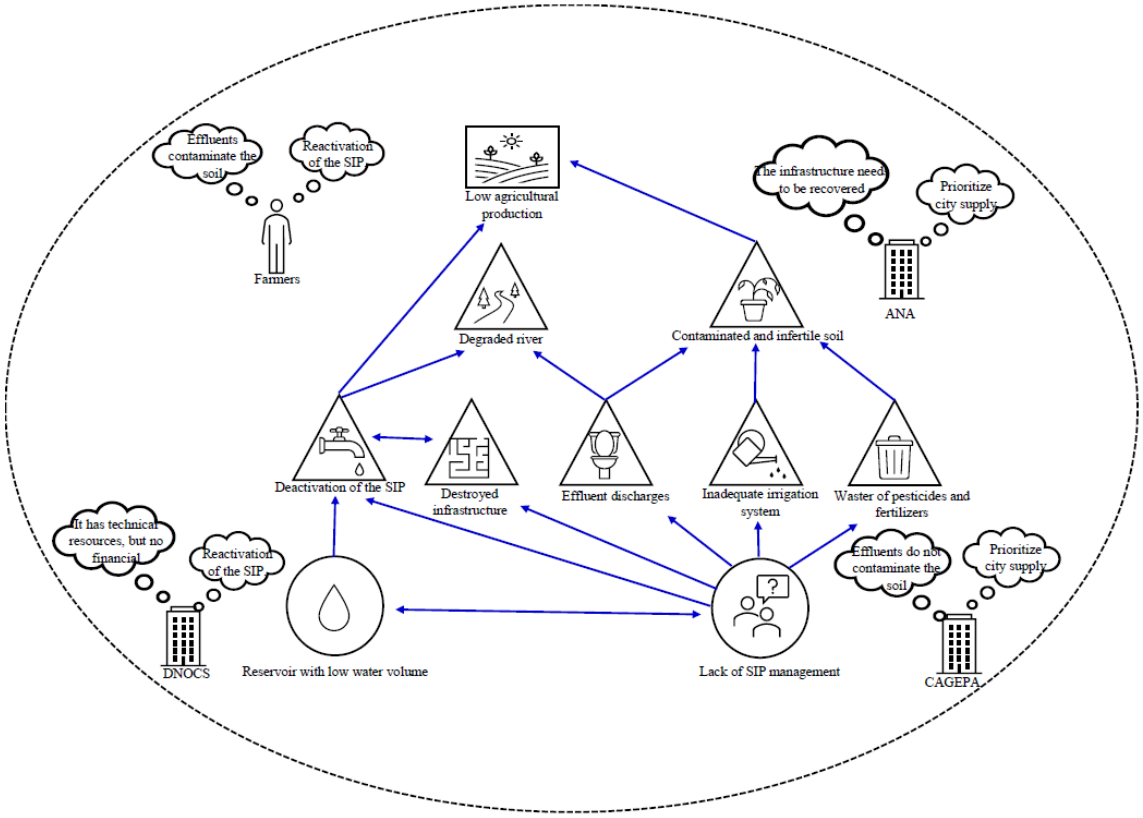


Figure 4: Rich picture of the conflict.

Based on the study by Pessoa, (2019), we identified a list of issues in the conflict in the SIP: (1) low volume of the reservoir; (2) deactivation of the SIP; (3) lack of a management plan; (4) reduction of agricultural production due to the interruption of irrigation; (5) degradation of the irrigation system; (6) the soil of some agricultural lots became infertile due to the irrigation model used by the farmers; (7) the soil of some agricultural lots is contaminated due to discharge of effluents, pesticides, and fertilizers; and (8) degradation of the area (banks are

polluted and the riparian forest is degraded). Thus, it was possible to construct the rich picture of the complex problematic situation (Figure 4). These issues were classified into root factors (issues 1 and 3), middle factors (issues 2, 5, 6, 7, and 8), and end factors (issue 4).

4.1.2. Construction of the conceptual model

At this time, the systems thinking starts. To illustrate the development of the conceptual models, one relevant system will be presented: "The low agricultural production" Firstly, the SSM formula must be used.

• P = What? P: To increase the agricultural production.

• Q = How? Q: Reactivating the SIP.

• R= Why? R: To improve the quality of life for the farmers, and to produce economic, social, and environmental benefits for the SIP region.

The appreciation of the system implied in the following root definition: A system, whose owner is the ANA, can promote economic, social, and environmental development of a region, located in the Brazilian Semiarid region, through the reactivation of the SIP. The CATWOE analysis is showed in Table 6.

Table 6: CATWOE analysis

ID	Issues	Analysis
C	Customer	Farmers, population of Sumé and the environment of the Sucuru River.
A	Actors	Farmers, ANA, DNOCS, and CAGEPA
T	Transformation process	SIP disabled → transformation→ SIP enabled
W	World view	The SIP is important for the development of the region and it is possible to reactivate the SIP.
O	Owner	ANA
E	Environmental constraints	Financial constraints, legal constraints, quantity and quality of water, quality of the soil, situation of the river, lack of management, lack of information.

This root definition led to us develop the conceptual model of the relevant system, as shown in Figure 5.

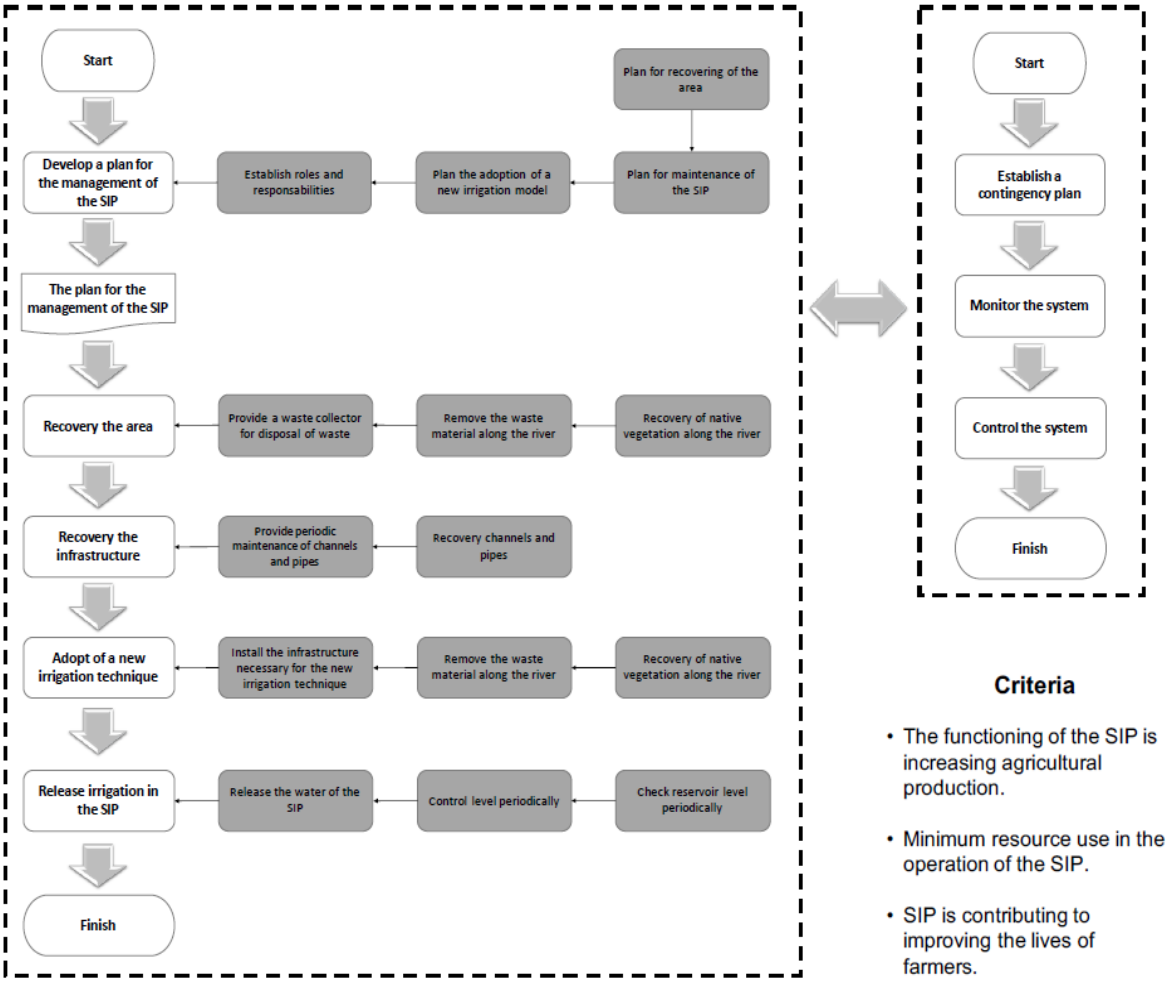


Figure 5: Conceptual model of activities in the SIP

Note that, the conceptual model of the relevant system is comprised of two systems: an operational system, in which are the activities necessary to enable the SIP; and a monitoring and control system, which aim to verify the activities realized in the operational system based on efficacy, efficiency and effectiveness criteria.

4.1.3. Establishment of the alternatives for mitigating the complex problematic situation

At this step, the complex problematic situation expressed in the rich picture (Figure 4) is compared with the conceptual model (Figure 5). The result of this is a list of possible actions for change that are both desirable and feasible to improve the problematic situation is presented in Table 7.

Table 7: List of possible changes to improve the problematic situation

Conceptual model	Problematic situation	What are the differences?	Is this issue important?	Possible actions for change	Is this change desirable?	Is this change feasible?	Actors responsible
Plan for the management of the SIP	Lack of SIP management	In the model, there is management, in the problematic situation, there is no.	Yes	Plan recovering of the area	Yes	Yes	Farmers, DNOCS, ANA, and CAGEPA
				Plan for maintenance of the SIP	Yes	Yes	Farmers, DNOCS, ANA, and CAGEPA
				Plan the adoption of a new irrigation model	Yes	Yes	Farmers, DNOCS, ANA, and CAGEPA
				Establish roles and responsibilities	Yes	Yes	Farmers, DNOCS, ANA, and CAGEPA
Recovery the area	Degraded river, effluent discharges, waster of pesticides and fertilizers, contaminated and infertile soil	In the model, the area is recovered. In the problematic situation the area is degraded	Yes	Recovery of native vegetation along the river	Yes	No	Farmers and DNOCS
				Remove the waste material along the rive	Yes	Yes	Farmers and DNOCS
				Provide a waster collector for disposal of waste	Yes	Yes	Farmers and DNOCS
Recovery the infrastructure	Destroyed infrastructure	In the model, the infrastructure is recovered. In the problematic situation. The infrastructure is destroyed	Yes	Recovery channels and pipes	Yes	No	DNOCS
				Provide periodic maintenance of channels and pipes	Yes	No	Farmers

Continued on next page

Table 7: List of possible changes to improve the problematic situation. Continued from previous page.

Conceptual model	Problematic situation	What are the differences?	Is this issue important?	Possible actions for change	Is this change desirable?	Is this change feasible?	Actors responsible
Adopt of a new irrigation technique	Inadequate irrigation technique	In the model, the irrigation technique is adequate. In the problematic situation caused damage to the soil	Yes	Train farmers on the new irrigation technique	Yes	Yes	DNOCS
				Acquire the infrastructure necessary for the new irrigation technique	Yes	No	Farmers
				Install the infrastructure necessary for the new irrigation technique	Yes	No	Farmers
Release irrigation in the SIP	SIP is deactivated	In the model, the SIP is active. In the problematic situation, the SIP is deactivated	Yes	Check the reservoir level periodically	Yes	Yes	Farmers
				Control reservoir level periodically	Yes	Yes	Farmers, CAGEPA and ANA
				Release the water to the SIP	Yes	No	ANA
Establish contingency play	There is no contingency plan	In the model, there is a contingency plan. In the problematic situation there is no.	Yes	Monitor the system	Yes	Yes	Farmers, DNOCS, ANA, and CAGEPA
				Control the system	Yes	Yes	Farmers, DNOCS, ANA, and CAGEPA

The following actions were considered not feasible because they depend on financial resources that are not available in the short and medium-term: recovery of native vegetation along the river; recovery channels and pipes; and acquire the infrastructure necessary for the new irrigation technique. The actions “provide periodic maintenance of channels and pipes” and “install the infrastructure necessary for the new irrigation technique” were considered not feasible because they depend on previous actions. The action “release the water to the SIP” was considered not feasible because the volume of the reservoir remains low.

Therefore, the recommendations to reactivate the SIP are divided into three phases: planning, execution, and monitoring and control. The first phase includes actions related to the development of the plan for the management of the SIP. The second phase includes actions for recovering the area and train farmers on the new irrigation technique that should be implemented just after the planning phase. Finally, the third phase is for controlling the reservoir volume.

5 Discussions

The SSM methodology was applied to structure a complex situation resulting from an environmental conflict in the Brazilian Semiarid region and the three main results of these steps were: rich picture, conceptual model, and alternatives. The rich picture is a description of the situation through graphical elements that are organized into levels, which shows the main issues and their relationships and actors involved in the conflict. It is constructed from different points of view and allows the group to achieve a holistic understanding of the situation and to change the perception about it. Then, it was possible to identify the relevant systems and to construct a conceptual model, which represents the ideal situation that would satisfy the interests of all stakeholders over multiple dimensions (economic, social, and environmental). In our model, the conceptual model is represented by a flowchart of activities, which were classified into three types: planning actions, execution actions, and monitoring and controlling actions. In the systemic world, pursuing these activities would invariably lead to the achievement of the final objective of the relevant system. Based on the comparison of the real and ideal situation, a set of alternatives is proposed. However, a set of constraints exist that hinds to achieve the ideal world. Then, it was observed what alternatives from the set are desirables and political, economic social, and environmentally viable in practice. In our model, the actors responsible for each of the actions are identified.

In the proposed model, we embedded the SSM methodology (phase 2) to comply with the organizational structure of the committees. After the formulation of the alternatives, which is the output of phase 2, in which SSM is applied, the model follows with the appreciation of these alternatives, as it happens in the plenary of the committees in practice (usually a simple voting procedure is applied), during plenary sections (phase 3). However, before the analysis phase, our model contemplates a phase that allows structuring all the steps that precede the analysis, from the identification of the complex problem to the creation of the working group and finally to prepare the logistics.

We believe that this three-phase model will make the decision-making process of watershed committees more effective. We can cite the main advantages of the proposed facilitation model: (i) learning about a complex problematic situation; (ii) the formalization of a process to help the decision-making about a complex problematic situation; (iii) the assignment of roles and responsibilities to actors; (iv) the availability of a set of tools that facilitate the structuring of complex problematic situations; and (v) flexibility, it can adapt to the needs of the committees.

6 Conclusions

This paper presents a facilitation model, based on the problem structuring method SSM, for supporting decision-making processes that occur in Brazilian watershed committees, which are entities responsible for the decentralized and participative management of watersheds in Brazil. The model comprises three phases: (i) pre-structuring; (ii) structuring the complex problematic situation, in which the SSM is applied; and (iii) appreciation of the alternatives. The model was developed in comply with the organizational structure of the Brazilian watershed committees.

The SSM methodology performs the analysis of complex problematic situations in order to promote a common understanding of them and then to identify the alternatives for mitigating the problem. In practice, this is what the plenary of the watershed committees do, but without a structured protocol that aims to conduct the process in order to achieve effective results, that is having a deliberation of the committee regarding the problem. It is also important to observe that the decision-making processes that occur in these committees are complex in nature, with a high probability of conflicts among their members. Thus, usually, we have complex problems being discussed in complex environments. Therefore, having a structured way that supports the analysis of the problem is extremely important.

To illustrate the use of the model, the SSM phase was applied to structure an environmental conflict regarding water and land sharing, in northeastern Brazil. We conclude that the model is a powerful tool for the analysis of complex problems, for which there is no consensus regarding alternatives for solving/mitigating it and/or there is a high level of uncertainties involved in the decision-making process. Since watershed committees are a complex environment that deals with complex issues, we believe that the model has the potential to be used by these entities in order to make their decision-making processes more effective. For future work, we suggest the application of the model with members of committees.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES).

References

Observation: The list of references is at the end of this document.

CHAPTER 5
FINAL REMARKS

1 Final Remarks

This thesis proposed a facilitation model based on Soft Systems Methodology (SSM) to support decision-making processes in Brazilian watershed committees. For this, three papers were developed. In the first two papers, we performed systematic literature reviews that were used as subside for the development of the proposed model, which is presented in the third paper. This section discusses the main results, highlights the contributions and limitations of this research, and makes recommendations for future works.

In the first paper, a literature review on PSMs was performed. Thus, it was possible to verify the increase in the number of publications on PSMs in the last decade. Most of these papers were developed in Europe and published in the European Journal of Operational Research. Furthermore, seven of the ten authors with the highest number of papers are affiliated to European universities. Regarding Brazil, it was observed that there is an increase in interest in PSMs. This means that PSMs have gained popularity, but studies are still mainly concentrated in the community of OR in Europe, particularly in the United Kingdom, where the OR revaluation movement started.

Thereby, PSMs have addressed problematic situations in different areas, such as: business management; environmental management; healthcare sector; and social issues. Moreover, SSM (by itself or in combination with other methods) has been the most frequently applied PSM. Thus, it can be concluded that PSMs are powerful tools to address complex problems in different areas. Moreover, this review showed, from studies that propose theoretical and methodological advances, that the research on PSMs remains evolving in the sense that methods must adapt to situations, and not the other way around. Development of multimethodologies and Behavioral Operational Research are evidence of that. Thus, it was concluded PSMs are a research topic with great potential in OR, and the findings of this review can be used as a starting point to new development in this field.

With that in mind and believing in the potential of using PSMs in Social-Ecological Systems, it was decided to develop another literature review whose object was to investigate the use of PSMs in Social-Ecological Systems (second paper). Thus, in this paper, it was possible to verify that the most applications occurred in Europe, and Brazil was the country with the greatest number of applications of PSMs in this type of system. Moreover, it was verified that SSM, is the most frequently applied PSMs in Social-Ecological Systems, followed by DPSIR (Drivers, Pressures, State, Impact and Response). Regarding application contexts,

most of the papers applied PSMs in problematic situations in hydrographic basins or groundwater management. Furthermore, most of the studies are related to the management of water resources.

Still in this paper, it was possible to verify that is common heterogeneous groups of actors participate in the intervention in Social-Ecological Systems, which makes the problem structuring richer. Usually, these groups are composed of representatives of government, the private sector, civil society, and specialists. In addition, it was observed that workshops and interviews are the techniques most frequently used in the reviewed papers to model the perceptions of these actors about the problematic situations. It is understood that collective and participative approaches, such as workshops, may be more appropriate to model the perception of the actors. As for the benefits of the models based on PSMs, the most frequently cited aspects are suitability for social-ecological systems problems, learning about the problem, engagement, and transparency. Time consumption and the lack of quantitative data seems to be the main limitations on the use of the models. Thereby, it was concluded that PSMs are very suitable for dealing with the inherent complexity of these systems. However, the use of PSMs in these contexts is still small and should be encouraged.

Consequently, the findings of the first two papers gave us the basis for proposing the facilitation model. Thus, in the third paper, it was proposed the facilitation model, based on SSM, to support decision-making processes in Brazilian Watershed Committees. To illustrate the applicability of the model, it was applied to structure an environmental conflict that exists in an area of the watershed of the Paraiba do Norte River, Paraiba State, Brazil. It is considered that the model contributes to formalize participatory and democratic decision-making in Brazilian Watershed Committees.

Given the above, it is considered that this thesis brought contributions both to academic research and to society, as the evolution of the field of PSMs was presented, the way these approaches were applied in Social-Ecological Systems and, the proposed model can improve decision-making processes on water resources in Brazil. The limitations of this research are due to only one database to conduct the reviews, although it was sufficient to achieve the objectives; the analysis carried out based on subjective reasoning and end up suffering interferences from the authors' biases, but it is considered that this has been softened with the creation of criteria and protocols; and because the COVID-19 pandemic, the activities of the Brazilian Watershed Committees were suspended, and it was not possible to apply the model with the members of

committees acting as facilitator and working group, as it is recommended in the proposed model. Lastly, for future studies, it is suggested to apply the proposed model in different committees, analyze the actors' perception of it, and based on that, propose improvements, such as the integration of other approaches.

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Appendices

Appendix I- Proof of submission of the 1st paper

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Full author list: Alexandre de Araújo Gomes Júnior; Vanessa Schramm

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