Systematizing the impacts projection of complex decisions in work groups

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Abstract

Complex decisions can give rise to unexpected consequences from implemented actions. The main problem discussed by this research is the difficulty suffered by decision-makers in projecting impacts of a complex decision before the decision occurrence. Unexpected impacts of complex decisions demand mitigating action so that it is possible to intensify the positive aspects and neutralize the negatives. Dealing with unexpected impacts generates a cognitive overload on decision-makers and on the availability of material resources. To solve these problems, this research proposes the impact projection of complex decisions in a collaborative way, to be applied before the decision occurrence. The proposed solution considers a systematizing project impact of complex decisions inside work groups and delivers a framework and artefacts to support decision-makers in their decision impact tasks before the occurrence of a real decision scenario. This solution was evaluated by decision-making specialists and their goal was to investigate the applicability of this proposal to different teams. This is a qualitative research, and the method applied was the case study because we would like to deeply understand the behaviour of this approach in decision-makers team. The evaluation generated evidence on the feasibility of this approach, showing that the artefacts provide a systematic structure to orient what decision-makers must do to know and understand the impacts of decisions before their execution. This evidence is contribution for decision support field.

Keywords Naturalistic decision-making · Group decision-making · Decision impact · Knowledge modelling

1 Introduction

Decision-makers face tasks that are increasingly complex, interrelated, and dependent on their individual characteristics and context [1–4]. A complex decision can be understood as a dynamic system that is composed of interrelated variables. The more interconnected these variables are, the more complex the system is. Complex decisions are composed of actions, and their complexity is in the surrounding environment, based on the context and behaviour of the individuals involved. In such a decision, it is difficult to isolate the elements that influence it. These decisions happen in series [5] and deal with uncertainty

[6]. Their impacts are interdependent, and the environment in which they are inserted generates constant change in the decision [7]. In this research, the definition of complex decision is based on naturalistic decision-making theory, which describes how decision-makers make decisions in the real world [8–10].

Information about complex decisions is a strategic resource. Initiatives that support and aid the decision-making process have been discussed. Most of them help decision-makers choose satisfactory alternative solutions and mechanisms that reduce negative implications and potentiate the positive implications caused by the implemented decision in the future [3, 11]. In this research,

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positive implications are actions that bring value and negative are actions that bring harm for the individuals and environment where the decision is sited.

Complex decisions sometimes trigger unforeseen consequences. Due to this challenge, some steps must be taken—decision process planning, potential risk analysis, and a mitigation plan—along with gathering specialists armed with information that is relevant to the decision.

Decision solutions are proposed and discussed during the planning phase of the decision-making process. Nevertheless, there are a few details about an implemented decision's future consequences. Some models commit to guiding a decision-making process, predicting the decision, and discussing future consequences without highlighting a systematized guideline [12], or present inferences based on similar previous cases [13–16]. When discussing complex decisions, new solutions need to be thought out and correlated with information already known. Some researchers defend the use of graphs saying it is to illustrate and make it easy to understand the data analysed by a decision-maker or team [17].

The literature discusses the need for collaborative strategies to support decision-making tasks. To minimize errors arising from individual decision-making, the authors [18] suggest the construction of an organized, systematic, and collaborative process to achieve better results. Research has been made to discuss the idea of collaborative environment and network to support decision-making field [19–21].

This paper focuses on the difficulty suffered by decision-makers in projecting impacts of a complex decision. So, it aims to answer the research question: Is it possible to support decision-makers teams in projecting impacts of a complex decision before its occurrence?

According to [22], collaboration is a promising mode of human engagement that has become a twenty-first-century trend. The need for think together and work in teams on critical issues has increased [23], causing to stress on from individual attempts to teamwork [24]. This research understanding that a group of decision-making thinking and contributing with their individual knowledge and experience can achieve better understanding of a complex decision and project the impacts of each decision on the environment.

The following hypothesis is investigated in this paper: Guiding the decision-making group and knowing the different perspectives of decision-makers in relation to a decision issue can support a collaborative projection of impact. Projection in this research is understood as an action made by decision-makers where they have an early idea of possible impacts of a decision action that can happen. Collaborative projection is an action where decision-makers team can work together to analyse a decision

question and investigate its impacts before the decision occurrence, based on decision-makers experience, knowledge and other resources discussed in this paper.

This research is an evolution of [25] and aims to propose a collaborative framework called Projecting Impacts of Complex Decisions (PICD). It consists of five modules and at its core is the Impact Model, grounded in the conceptual structure called Characterization of Impact Projection. The impact model is a structure developed to support decision-making teams discuss and develop complex issues, especially decision impacts. To orient this model application and other activities to support impacts explicitness, this paper proposes a process. We understand that these artefacts are ways to guide decision-makers into their decision impact tasks before the real occurrence of a decision scenario.

This research aims to provide ways to solve problems faced by decision-makers into their activities, related to complex decisions, as: (1) It is not common for decision-makers teams discuss the possible impacts of a complex decision before its execution. The framework provides the impact model and a process to orient the systematizing of this discussion, decision analyse, and impact projection. (2) Lack of individual resources, knowledge, and experience to discuss and analyse the decision question (concerned to the decision impact). PICD framework proposes a collaborative approach and the interactions between decision-makers can heal this kind of problem. (3) Unknown is the behaviour of a complex, but common, decision action in an environment. We claim the framework PICD can support this problem with the decision impact data base. In it, it is expected that models of complex decision impact are managed.

To investigate the applicability of the proposed solution, the case study method was applied in five teams, using the developed artefacts. Since complex decisions are found in dynamic environments, decision-makers were invited to contribute to this research. Five decision groups from a public organization in Brazil took part in this investigation. This study's aim is to evaluate the framework proposed through the observation of the impact model applicability. The results showed that PICD proposes a systematic way to project the impact of complex decisions through specific models able to orient decision-maker teams to project impacts of complex decision before its occurrence. This paper brings contribution to decision support field, especially to naturalistic decision-making (NDM). This paper is organized into: Introduction, Materials and methods, Results and Discussion, and Conclusion.

2 Materials and methods

2.1 Impact concept background

Impact is understood as the measure of tangible and intangible consequences of something on another. According to Hammond [12], to achieve smart choices, it is necessary to compare the merits of the known alternatives, assessing how well each one satisfies the decision's fundamental goal, and analyse the consequences of each decision taken.

Complex domains, like urban planning, resource management and emergency response decision-makers [26–28], have suffered setbacks in controlling these system behaviours and, consequently, unfolding the actions taken [28, 29]. In all these domains, decision-makers find it difficult to anticipate the secondary effect of interdependent decisions taken and predicting their mid- and long-term impact. This difficulty has translated into serious negative consequences for the system [7, 11, 25, 30, 31].

Some authors assert that it is possible to analyse the impact of a decision implemented through decision process monitoring [12]. However, it is necessary to wait on the occurrence of the decision's impact before introducing solutions for the damage or improvements on the environment and its components. Still, there are other works that support an impact analysis beyond inference and quantitative results. It is possible to find in the literature, works that discuss the decision impact in the beginning of decision analyses, like those on the decision process planning phase [12, 29]. Furthermore, most research in this area do not highlight details about how to effectively project impacts in practice as much of the focus is on the impact of complex decisions. Most of them deal with impacts projected in a subjective way, intrinsic to the decision-maker's experience and their mental correlations (cognitive structures, mental models) and intuition, regarding decision-making [30, 32]. According to [7], the mental representations involved in dynamic systems and exercises are inadequate. The so-called mental models, intended to attempt to mentally replicate the relationship structure of a complex system, play an important role in the decision-maker's orientation. However, it is difficult to ascertain if the externalized verbal or diagrammatically mental model corresponds exactly to the existent mental model in the individual human mind.

Decisions approaches like those proposed by [12, 13, 15, 29, 33] while considering the decision impact projection, do not define how this action should be conducted. In some cases, without considering how they are

externalized or represented, it is up to decision-makers to choose how best to meet their expectations. This freedom of action, in relation to complex decisions, can hamper decision-makers since they must organize the information and make the decision based on their cognitive effort and mental organization. The results found in [12, 13, 29] show the potentialities when decision-makers work collaboratively.

The models and strategies discussed in the literature and presented in this section demonstrate the existence of the support that surrounds complex decisions and their consequences. Despite this, little work has been done on systematizing the impacts projection of complex decisions during the planning phase of the decision-making process, considering the knowledge and experience of the decision-makers involved. In the follow subsection we present the research methodological structure that guides the development of this paper.

2.2 Research methodological structure

Designing the impact of complex decisions is a dynamic action that requires decision-makers' knowledge, experience, time, coordinated action, and cognitive resources. In order to help decision-makers to implement activities related to complex decisions consequences, it is necessary to understand the elements that characterize the impact projection of these decisions and to provide a solution that facilitates the impact's identification and analysis. Bearing this in mind, this research invested in: (1) the construction of a conceptual framework for Projecting Impacts of Complex Decisions (PICD); (2) making the PICD explicit for decision-makers through the proposed artefacts; and (3) provide a support for decision team interaction;

The methodological structure designed for this research is present in Fig. 1. As it is possible to see, this research is organized in three phases: context, solution, and evaluation. This is a qualitative research and specialists will participate in this study.

The main contribution of this research is the PICD framework. It plays the role of organizing the knowledge involved in this type of projection, whereas the impact model initiates the framework, making explicit the impacts projections identified, discussed, and analysed by the decision-makers. Due to the dynamism of the environment in which complex decisions are made, the analysis and discussion of the decision group are geared towards considering different visions, knowledge, and experiences about the complex decision. Already, this paper solution guides decision-making groups in analysis and impact projection. In the following subsections, the conception and details of the elements that make up this research's proposed solution are presented.

Fig. 1 Research methodological structure **Fig. 2** Method to construct a general conceptual framework (GCF) [35]

2.3 Conceptual framework for projecting impacts of complex decisions (PICD)

A framework is a set of reusable objects that encompasses the knowledge of certain areas and applies it to a specific domain [34]. The General Conceptual Framework (GCF) [35] (Fig. 2) was applied to support the development of the Characterization of Impact Projection module of PICD framework. This model is the heart of the PICD framework and brings important knowledge to be applied in the development of the other modules.

GCF consists of eight phases: (1) conceptual framework planning, (2) investigation/adaptation of existent methods, (3) information research of related concepts, (4) definition of the framework categories, (5) definition of the

framework concept structures, (6) establishing interaction with stakeholders, (7) conceptual framework construction, and (8) disclosure of the conceptual framework.

The first three phases were executed sequentially, while the fourth phase to the seventh phase occur cyclically. The method outlines the proposal for each phase, but it is up to the executor to detail or summarize the execution of each phase, according to the demand of the framework to be constructed. The GCF guided the construction of the PICD's Impact Projection Characterization module.

The PICD framework (Fig. 3) consists of four main modules: (1) characterization of impact projection, (2) establishment of metrics, (3) impact model, and (4) knowledge bases. Each module represents a specific part of the complex picture that is the projection of a decision's impact. To

Fig. 3 Conceptual framework for projecting impacts of complex decisions (PICD)

consider the complexity present in the impact's projection, it is necessary to think about an initiative that will make the use and evolution of the framework more flexible.

Modularizing the concepts and relationships inherent to this projection is an initiative that reflects the needs of this environment, minimizing the difficulty in acting on complex decisions when considering their characteristics, especially their dependency. With this strategy, it is possible to isolate the elements in layers and define the relationships between them, promoting greater use flexibility of the conceptual structure and its evolution. The four main modules were proposed based on [5, 36] that are literature discussing complex decision inside naturalistic decision-making field. In there, the authors defend the decision-making team, knowledge bases of decision-making, knowledge organization (mental models can be a strategy), and decision rate as a path to support complex decision-making. In this paper, solution we are discussing these four modules of PICD in an impact projection view.

The knowledge bases module aims to engender environments that support decision-makers in their tasks. It is composed of three bases: projection base, decision structure information, and contextual information. The first base aims to manage the impact projection developed to support the applicability in other instances and promoting impact reuse. The decision structure information is a base to inform the decision data, concerned with goals and detailing of the decision question. The third base aims to manage the contextual information, that is, all the external and internal influences on a decision. It can be the

decision-maker's experience, intuition, and background, and the financial resources available. Contextual information can be understood as tacit or explicit knowledge concerned with a decision.

The characterization of impact projection module plays the role of organizing the knowledge involved in the impact projection at three levels, detailed in the knowledge structures. The context level brings the semantic load on the environment in which the decision is inserted, presenting the concepts and relationships intrinsic to this medium in a generic way. The collaborative impact projection level considers the impact projection characterization from the perspective of agents. The third level represents the instantiation of the impact projection characterizing elements. These elements' externalization is handled in the applicability of the impact model (Sect. 2.3.2 and Table 2).

The impact metrics module aims to assess each decision-analysed consequence, considering its influence on the environment, on new actions, and on the individuals involved. The impact model makes up one more module of the framework. The impact model structure contemplates the constructs that adhere to the knowledge organization proposed in the characterization of impact projection module. Although every model requires a notation for its representation, this research will not delve into the best representation of the impact. Our focus is to propose a way to make explicit the interest knowledge. The knowledge base module is to maintain the existing decision impact projections, and the contextual and structural information. Next section we present the development of the characterization of impact projection module. This PICD module was constructed based on GCF framework.

2.3.1 Development of the characterization of impact projection module

The main goal of the PICD framework is to establish a support system for decision-makers to make impact projections in complex environments. It is the result of GCF's phase I.

Phase II aims to verify if the GCF method is appropriate for developing the interest framework. Since this method provides, in detail, the concepts organization and direct contact with stakeholders, it is understood that it is enough to proceed with the present investigation.

In phase III, a literature review of the definition, characterizing elements, and themes applications was carried out on complex/dynamic decisions, naturalistic decisions, decision-making, context management and collaboration applied in different domains. These themes were selected because they are related to the impact's projection in complex environments. Also, in Phase III, structured interviews were conducted with five real decision-makers

Table 1 Origin of structural concepts for the composition of the characterization of impact projection module

Characterizer elements	Competence questions	Knowledge structure (concepts)
ill-defined goals	How is the low structure of complex decisions handled in order to project impacts?	Socialization, Protocol, Collaborative session
Knowledge of the decision-making process with continuous change	How is knowledge represented in low-structure environments?	Message, Characterizer
Dynamic and uncertain environment	How are dynamics and uncertainties handled in projecting the impact of complex decisions?	Impact, Impact Type, Result
Feedback loop	What are the internal and external influences that complex decisions suffer?	Decision-maker, Sender, Receiver
High risk	What is the relationship between risk and the projection of impacts on complex decisions?	Objective, Advantage, Disadvantage
Multiple decision-makers	What are the contributions of those involved in the complex decision? What are the types of stakeholders?	Decision-maker, Sender, Receiver
Organizational context and rules	Which elements allow the organization's contextualization in relation to complex decisions?	Scenario, Alternative, Fact, Characterizer
Real time	How to make complex decisions in real time?	Characterizer, Objective, Advantage, Disadvantage, Message
Decisions are composed of several decisions	How to isolate actions from decisions?	Scenario, Alternative, Impact, Characterizer, Implication, Metric
Dependent decisions	How to make explicit the dependence between decisions?	Alternative, Characterizer, Communication, Perception, Socialization
High cognitive workload	What are the contributions of decision-makers in projecting the impact of complex decisions?	Communication, Perception, Socialization
Ambiguous and incomplete information	How to deal with the lack of information in order to project impacts of complex decisions? What elements can contribute to minimize the ambiguity of information involved in complex decisions?	Communication, Perception, Socialization, Scenario, Alternative, Message, Objective

acting as manager, coordinator, or analyst in public and private enterprises in Brazil. The goal was to deepen the characterization of the problem investigated in practice by this research. It is important to highlight that although we have interviewed in person five decision-makers, all of them have more than 10 years of experience as this role. It was a satisfactory sample to characterize the problem faced by them, concerned to complex decision analysing and impact discussion.

The theoretical and practical search generated a set of elements that characterize complex decision analysis comprising Phase IV of GCF. The characterizer elements discovered are: ill-defined goals, knowledge of the decision-making process with continuous change, dynamic and uncertain environment, multiple decision-makers, feedback loop, high risk, organizational context and rules, decisions are composed of several decisions, dependent decisions, high cognitive workload, ambiguous and incomplete information, and interaction among

decision-makers. These elements are results from a qualitative treatment on the theoretical and practical search. The interview and theoretical investigation reports were analysed and categorized by the author of this paper to achieve the elements above.

During Phase V, the set of characterizing elements discovered in phase IV were analysed in order to generate a set of competency questions that focus on knowledge organization for the projection of impacts. In total, there were 16 competence questions related to 13 characterizer elements (Table 1). These questions were generated from the relationship between the characterizing elements and what one wishes to solve based on the results of the conceptual framework planning (Phase 1—GCF). The concepts (knowledge structure—Table 1) are the solutions for the competence questions. This result was achieved based on the knowledge developed by the authors on the practical and theoretical search and presents the inputs for the characterization of impact projection PICD module.

Fig. 4 Context characterization to impact projection (Level 1)

The module characterization of impact projection presented in Fig. 3 provides the necessary structure for the other modules that compose the PICD framework and the orientation method to support decision-makers. Level 1 of this structure reflects the context in which the complex decision is inserted. Its purpose is to conceptualize, generically, how the impact behaves in distinct scenarios, and highlighting its influences without associating it with any specific system or approach. Figure 4 depicts the context characterization, based on [37, 38], resulting from the application of the GCF method. In it were incorporated the concepts impact, result, impact type and their dynamics of action. Contextual elements are entities that can be considered to manipulate context information. Based on this, impact represents the degree of importance of a contextual element on a situation, characterized as impact type. According to the model, every task has an associated result. It is run by agents and aims to achieve a result based on its goal. The focus of a task defines the contextual elements used in its characterization.

The second level is dedicated to specializing the first, with special attention to the impact projection of complex decisions. This level acts in the characterization of two main and actively associated segments that are the collaboration and the decisions impact. Collaborative actions are justified in this proposal based on the characteristics raised by the complex decisions and related themes in the fourth phase of the method. Multiple decision-makers interacting in complex decisions tasks awaken the possibility of generating information and results to be known. However,

this interaction requires orientation and coordination of actions to support the development of relevant results. This orientation will be discussed in Sect. 2.3.2 using the Impact Model, especially Fig. 6. This model orients the concepts that the teams must think and discuss during the impact projection meeting. It inserts a coordination of tasks for the decision-makers involved, and this artefact structure was developed based on the characterization of impact projection provided in the PICD framework.

The positive aspect of the knowledge structure supports a collaborative impact projection. This allows an oriented analysis impact projection of complex decisions, avoiding the loss of the knowledge built. Figure 5 presents the knowledge structure of Level 2, considering the concepts (results of the competence questions presented above), their relationships and the already-consolidated knowledge structures on collaboration [39] and decision [3]. The third and last level translates the instantiation of Level 2, in order to make explicit the knowledge built during the collaborative session on projected impacts.

The conceptual structures proposed in the characterization of the impact projection module were defined based on the knowledge built from the previous phases' results of the GCF method, and from the conceptual elements mentioned in the interview (Sect. 2.1). The contact with real decision-makers (the stakeholders in this case) makes up the sixth phase of the GCF. In this development, we contacted in phase VI the same decision-makers that we interviewed in phase III. However, in phase VI our goals were related to investigate the value of the characterization of

Fig. 5 Knowledge structure for collaborative impact projection (Level 2)

impact projection module in organizing the main concepts applied and faced by decision-makers in practice to analyse a decision question and project its impacts. This contact in phase VI was a meeting with each decision-maker participant. The data collected were analysed by the meeting mediator and a few improvements were made in the structure (mainly Fig. 5). The changes did not introduce new concepts but improved the relations between them. The information collected and analysed during the GCF execution contributed to introduce improvement for the Characterization of Impact Projection PICD module. It corresponds the seventh phase of GCF.

The framework's goal, beyond projecting impacts from complex decisions, is to retain the constructed knowledge and, thus, the need for the impact projections basis maintained by the decision-making team. Because these are highly complex decisions, there is a need for decision information and the context in which the decision takes place. Therefore, the framework considers the knowledge bases of the decision structure and the context. These resources are usually known to some decision-makers that compose the group. The different knowledge and experiences of those who make up the decision group bring a more comprehensive knowledge about the decision and its impacts.

The framework also considers the impact model module (discussed in the following subsection) and the metric module that translates the implications of the alternatives

analysed by the decision-makers into a value. This value is defined according to a significant scale proposed by the decision-makers and, therefore, can be modified according to the model's instance. The eighth and final phase of the applied GCF method is detailed in the following subsections with the artefacts (process and model) produced to apply the framework in practice.

2.3.2 Impact model

As an initiative to externalize the knowledge from the impact projection of complex decisions into models, we decided to apply the well-known principles of the Mental Model structure [40, 41]. The difference lies in the introduction of an orientation for the decision-makers' reasoning, through the proposition of constructs to organize the impacts projection knowledge. As we know, mental models do not have defined structures, it is a free composition. In this research, we assume that the support given by mental models in identifying new perspectives is interesting, but an orientation of the issues that must be discussed can support the impact projection tasks. For this, the impact must have defined constructs based on Fig. 5 of this work.

Table 2 Relationship between knowledge structure for impact projection and impact model

Knowledge framework for collaborative impact projection	Impact model constructs	Impact model attributes
Scenario	Scenario	–
Fact	Decision	–
Alternative	Alternative	–
Implication	Implication	–
Metric	–	Metric
Impact	Impact	–
Characterizer and leaf concepts	–	Characterizer

(a) Impact projection

The role of this model is to organize the knowledge developed during discussions about the decision among the decision-makers, favouring the retention of the knowledge developed by the group and the impact definition of each complex decision alternative. In Fig. 6a, a decision is consisted of scenarios, which are used to estimate the likely effects of one or more variables and are an integral part of the situation analysis and decision planning. Scenarios in this proposal compose the simulations activities of some possible futures. Each scenario consists of a set of alternatives proposed by the decision-making group, and each alternative will result in an associated implication. Alternatives are the possible actions that can be executed to implement the decision question, whereas the

(b) Value attributed to each alternative.**Fig. 6** Impact projection structure (Impact Model)

As Fig. 5 is the basis for impact projection, the Impact Model must consider it in its constructs.¹ Table 2 shows the correlation between the knowledge concepts structure to projected impact and the proposed constructs to compose the impact model. Although every model requires an associated notation, this research will not detail an investigation of the best notation, but rather will use a proposed and simple notation. Figure 6 shows the impact model prototype, with the predicted constructs and relationships. This structure consists of artefacts used by decision-making teams to project impact and applies the principles of the PICD framework.

¹ An idea or theory containing various conceptual elements, typically one considered to be subjective and not based on empirical evidence.

implications are the possible consequences considering each alternative action. Figure 6b continues the impact projection definition and analyses started in Fig. 6a. Here, each implication has a metric associated and represents the level of impacts of each alternative. To value the implication, a measuring scale defined by the decision-making group is proposed. Finally, the alternative impact is informed, and its calculation is done based on the metrics established in the discussion performed by the decision team on each implication. The usage of the PICD framework and consequently the models associated can be observed in the example scenario below.

2.3.3 Applicability of a case: impact projection structure

This section illustrates the use of Fig. 6, which contains artefacts that represent the conceptual structures

Fig. 7 Impact design using structure presented in Fig. 6a

developed and part of the PICD framework. Our purpose is to highlight the kind of decision knowledge that can be retained to support decision-makers in their tasks.

Consider the following scenario: A fire has broken out in your office building. This structure has three floors and you do not know where the fire is focused. You are part of a decision-making team for emergency situations, and it is your responsibility to save as many people as possible, including yourself. To help decision-makers know the impacts/consequences of an action before its occurrence, it is necessary to think about strategies. One such strategy is to stimulate interaction with other decision-makers and specialists. The diversity of knowledge can help with new discoveries (new impacts). Another strategy is to indicate what actions must be taken, bearing in mind the future, and discovering and reflecting on (before the action happens) what the consequences of the actions are on the environment.

In the scenario painted above, it is expected that the decision-making team would reflect on things like, but not limited to: (1) if the fire's focus is on the roof, the victims should be directed to the building entrance to avoid loss of lives; (2) if the fire's focus is the kitchen, located on the second floor, firefighters should be called because the place has gas canisters and the probability of an explosion is high. Besides, the people on the third floor should be taken to the roof and those on first and second floors should be saved using the building entrance. According to these reflections, there will be more resources to orient the actions and solve problems. In this research, we expect

that the PICD framework and artefacts proposed would guide decision-making teams in their tasks of projecting the impact of complex decisions.

In this scenario, decision-makers think about the possible consequences of a decision question, applying Fig. 6 structures. This was an exploratory example, run with a team composed of four decision-makers. Section 3 presents the studies, considering this same scenario, but with more criteria and details about the impact projection.

Figure 7 presents the results achieved in this exploratory example and is concerned with identifying the impact of the decisions in the preliminary phase of a decision-making process. The goal here is to present how the impact model can be designed by a decision-making team.

Figure 7 shows that the orientation of what kind of concepts the decision-making team must think, supports the design of the possible paths that can be followed to solve a decision question. All implications in Fig. 7 (last level) were proposed considering the previous alternative. Another important finding in this case is that this impact projection structure works only with data input by participants. The structure of Fig. 6b was applied in this case and Fig. 8 shows the results.

In Fig. 8, the impact is calculated from the weights reported for each implication. In this case the possible weights were a scale from 1 to 5, but each decision team can choose their weight scale. The lesser the weight, the lesser the impact of the associated alternative on the environment, according to decision-making team. The weights

Fig. 8 Value attributed to each alternative

provide a way to quantify the impressions of a decision-making team about the decision impacts analysed. The next subsection presents the process developed to guide decision-maker teams, showing the activities that must be performed. The impact projection structure design is considered in this process, in addition to the creation of decision-making teams and the management of the resources developed in this process' execution.

2.4 The decision-making group orientation process for impact projection

To guide the decision-making group in the impact projection activities, the impact projection orientation macro-process (Fig. 9) is proposed. It consists of four main sub-processes: establish a decision group; plan an impact analysis; design an impact; and report impact. This method is based on the PICD framework. The resulting product from the definition and impact analysis, by the decision group, is the collaboratively constructed impact model.

An analysis of the four sub-processes that comprise the impact projection orientation shows that two are essentially collaborative. Both the planning and projection sub-processes use the decision-making group components knowledge to execute them. Their results originate from the collaborative activities performed by the decision-makers. The other processes present activities that can be performed in a collaborative way, but this is not an

obligation. Participants in the decision group may take on individual roles.

Decision group establishment demands that organizers have an understanding of the decision. To accomplish this task, it is necessary to consider its structure through the objectives to be achieved, rules to be followed, the necessary resources and the problem to be solved. Based on this information, the decision-making group participants were selected and the interaction protocol between them established. All involved agreed on this protocol, building an egalitarian environment conducive to decision discussions. Planning the impact analysis promotes decision detailing, incorporating the analysis of contextual information. This planning also considers the previous experiences of the decision-makers and the development of knowledge uniformity until this moment in the decision group.

The first activity foreseen by the impact projection is to make known the impacts projection goals in the decision group. Then, the decision-making group performed three more activities, which are scenario constructions for the impact analysis, alternative definitions for the projection, and the association between alternatives and scenarios. This sub-process execution was accomplished through the impact model collaborative construction.

Once the alternatives were defined, two new activities were performed: (1) a search for existing impact projections that favour the impact's reuse, and (2) the definition of possible implications. At the end, the decision-making group analysed the implications, defined the alternatives

Fig. 9 Impact projection orientation process

impacts and finalized the impact model. It is up to the impact report sub-process to construct the reports of the projection process and feed the impact projection base. In this final report, decision-makers can find the elements introduced into the model and their descriptions, including the statistical numbers of each category (i.e. alternatives, questions, impact and implication). It is possible to find the weights of the represented implications in these numbers, their influence on the decision and the environment analysed.

The goals of this process are concerned to the orientation of decision-makers team into their tasks to analyse and project the impacts of complex decision before its occurrence. The impact model, that is developed guided by this process, presents the potential alternatives to solve the decision question analysed and what are the possible implications of these alternatives in the future. The impact model can provide a picture of the negative and positive implications of a complex decision. This information can support decision-makers selecting the satisfactory alternative and mitigate the implication until its occurrence in the future. So, the nature of these implications is events that can happen after the decision occurrence. The impact is a

metric to rate the influence (higher to less) of the implication in the environment.

3 Results and discussion

The conceptual PICD framework was produced with the purpose of offering elements that add facilities to the activities performed by decision-makers that relate to complex decision-making. This framework's focus is to provide resources that assist decision-makers in the analysis of complex decisions and in their projected impact, during the planning phase of the decision-making process. To evaluate the PICD framework and its artefacts, a case study was conducted in five groups and the research applied and techniques are presented in Fig. 1.

This evaluation had four specific goals: (1) experience the applicability of the impact model to support decision-makers in projecting the impact of complex decisions; (2) verify that the knowledge organization proposed in the impact model contributes to the establishment of collaboration between decision-makers; (3) verify if the impact model adheres to the impact process (Fig. 9); (4)

investigate the applicability of the PICD framework and its artefacts considering teams with different arrangements. The phases that compose the whole study were analysed considering: (1) the data collected from the teams' observation by two experienced observers; (2) the model constructed by them; and (3) the answers on a form about the experience of each participant during the study.

The observation research technique was conducted by two observers, seniors in research method. The goal here was to identify: (1) if all constructs of impact model were applied; (2) if the sequence of the impact projection make sense for the participants; (3) if the process (Fig. 9) orients the impact projection; and (4) if the teams achieve an acceptable interaction protocol.

The participants are current decision-makers from the same Brazilian public institution, and they played the following roles: administrator, technician and researcher. The group acted in a simulation where they needed to collaboratively design the possible impacts. They had to work on the following simulation: "How would you evacuate your current office building, affected by fire, preserving your life and saving as many lives as possible?" The decision is complex as it meets the characterization presented in the first sections of this paper. This decision question was proposed to be discussed and had its impact projection performed during this study. Although an evacuation plan is not an innovative or unknown issue, this evaluation seeks to discover another step in the complex decision planning phase. This study aims to evaluate and prove the proposal presented at the beginning of this section.

3.1 Evaluation preparation

For each team, the whole study was divided into three parts. The first was conducted by the study mediator through the implementation of the establish group decision sub-process. The second comprised the planning and design sub-process. To finish, we investigated the decision-makers' experience during their participation, with the purpose of validating the PICD framework and related artefacts, as well as discovering aspects for its evolution.

The evaluation study lasted 1 h and 10 min and included the participation of five teams. It happened in person, but details of the impact model and process (Figs. 6, 9) and this research goal were sent by email a week before the evaluation day to all participants, including a description of the impact model's construct and the process' activities. As soon as all participants accepted the invitation, the mediator scheduled a face-to-face study. On this day, the mediator divided the participants into teams and presented the study's goals, rules, and answered questions about the impact model and process sent by email. This

introduction part focused on organizing the study and took 30 min.

We invited 22 decision-makers for the study but only 17 participated. The other five blamed inability to make time from their schedule for the research study. All the invited people were selected based on their experience (in different levels) in decision-making and emergency situations. Some of the 17 participants knew each other before this research study, as they worked together at previous jobs. However, two participants met each other during this research study.

For this research, each group represents a case study. Group I consisted of five decision-makers who played the administrative and technical roles with more than 15 years of experience in decision-making processes. Group II was comprised of three decision-makers who played research roles in emergency management and decision support areas, with experience ranging from 2 to 4 years. Group III was composed of a pair of researchers in the emergency management area with experience between 3 and 4 years. Groups IV and V were composed, respectively, of three and four participants. They are trainees in the same area as Group II. It is important to highlight that the groups were arranged based on participants' experience, the rapport between them and group size. The groups were formed in a way where only one unknown participant was considered per group, if necessary. It happened in Groups I and II. These are valuable variables for this study because we want to understand what kind of size and experience better behaviour in decision' impacts discovery, discussion and projection.

Participants were informed about their tasks. The main one was the impact projection of the proposed decision question, considering the representation structures, presented in Figs. 6 and 9, and the plan impact analysis and design impact sub-processes. However, the interaction protocol between the participants of each group should be defined by them, as long as it respects the delivery of the interest product. The expected product of each group is a collaboratively designed impact projection model. The mediator informed each group they can access any information they deem necessary, consult partners and interact in their group in any way they deem appropriate. To build the impact projection model, paper, post-it and colour pen were made available for the teams.

The mediator presented the correlation between the predicted constructs of the impact model and the corresponding post-it forms for the representation during the study. During the study, the teams had to report the impact metrics as an attribute of the implication construct. Three possible values were defined: regular implication (value 1); low impact implication (value 2); and high-impact implication (value 3). With these values in hand,

the groups were able to calculate the impact of each alternative.

The second part of this study was the impact projection, comprising the planning and design sub-processes (Fig. 9). At this stage, lasting 40 min, each group conducted the impact projection considering this study's orientation and the structures proposed in this research. The mediator did not interfere in the groups' interactions and assumed an observer role during the activities carried out by the teams.

3.2 Impact model building and observation results discussion

To build the impact model, the teams ran the plan impact analysis and the design impact sub-processes. For the plan impact analysis, each group performed three activities: (1) decision detail; (2) make known decision-maker's experience; and (3) standardized decision and contextual protocol.

Group I was composed of participants that were more experienced in decision-making activities. During the plan impact analyses sub-process, three activities were accomplished. For the decision detailing (Activity 1), the participants interacted and established a common understanding in the group about the decision question. To facilitate the process, the participants shared experiences acquired in similar decision situations (Activity 2). This activity goal was to encourage the transfer of experiences among other components to prepare them for future activities.

The interaction protocol initially sought by the group was the consensus. However, the personal characteristics of each participant acted as facilitators in some moments and difficult in others (Activity 3), as reported the observers. In general, Group I had two participants that were more actively during the study. During the observations, it was clear that the personal characteristics of each participant interfered directly with their performance. The most expansive participants annulled the other participants' performance. On one hand, a participant tried to convince the group, but his ideas were far from the focus that was being discussed. On the other hand, another participant tried to establish the previously defined interaction protocol. As both decision-makers had strong personal characteristics, the discussion was intensive and the projection impaired. The other participants interfered very little in the discussions. At the end of the study, there was a group interaction initiative to construct the model, but the participants developed the phenomenon characterized by premature definitions to avoid conflict between the members. Thus, despite Group I, being composed of experienced professionals, it resulted in a low interaction among the participants and a poor impact projection,

Table 3 Quantitative contributions of the participating groups

Constructs	Group I	Group II	Group III	Group IV	Group V
Alternative	4	6	4	5	4
Implication	3	12	8	5	5
Scenarios	2	2	1	6	3
Characterizers	1	0	8	6	5

compared to other teams. It was clear that the knowledge standardization (Activity 3) was not enough to overcome the decision-makers' differences.

Groups II, III, IV and V performed the plan impact analysis sub-process activities in a similar manner to Group I. All groups established consensus as the initial interaction protocol. However, they had difficulty following it during the planning and design sub-process execution due to the characteristics of the participating decision-makers. In Group II, the most experienced decision-maker played the facilitator role for the group discussions. Through his guidance, the discussions were held, and the expected product was produced. Group III, was the one that presented the interaction process most cohesively. Considering the observation results, it was clear that the good understanding in Group III discussions was due to a similar mental configuration: a joint organization of their actions and a small decision group. Even the differences in the individual characteristics of each Group III member did not prevent achievement of the objective and smooth task conduction.

Group IV had a similar experience to Group III. The mental configuration of the participants was similar. They were able to establish group interactions in a calm and objective way. There were no termless discussions as in Group I, and all the participants externalized their previous experiences and their point of view on the decision. As a result, Group IV achieved more complete artefacts in the study, compared to Group I that was composed of more experienced decision-makers.

Finally, Group V faced the same difficulties as Group I. One of the participants was authoritative, aggressive and incisive in exposing his ideas and trying to guide the group. However, two other participants were more confident and rational in questioning the impositions made by the group's self-appointed facilitator. The group was able to complete the task satisfactorily, even in an unstable environment. The fourth participant, who presented personal characteristics of shyness and insecurity, was annulled by the intense atmosphere in the group.

The same interaction characteristics observed during the execution of the plan impact analysis sub-process were observed in the execution of the design impact sub-process. The impact report process was not fully evaluated

in this investigation. Only the first activity was performed by the participants. The impact models built during the study followed the structure proposed in Fig. 6. Table 3 presents the quantitative contributions of each group during the impact model construction. Observing this table, groups with participants acting as facilitators (like Group II) produced more detailed impact projections, whereas experienced groups (Group I) faced interaction problems. Another aspect to be highlighted is that less experienced groups (Groups III, IV and V) can produce detailed projections.

All the impact models (the bases are shown in Fig. 6a) constructed by the groups were analysed by the researchers. These analyses were necessary to understand if the models developed presents a rational idea of the implications provided and if all the constructs and the dynamic proposed (process) gave support to the decision-maker teams in their tasks.

Group I produced an incomplete model, detailing only one alternative proposed for the first scenario. As instances of the analysis were developed by Group I to construct the impact model, the lobby and library were obtained as scenarios. It means the group worked with two different analyses possibilities: fire focused in the lobby of the office building, and fire focused in the library. The first possibility considers the fire is focused in the building main exit, whereas the second considers the fire is focused in the middle of the building. The proposed alternatives were: break the lobby door, associated with the lobby scenario, and the others that follow without association to the proposed scenarios: gather people, sound the alarm, and use the extinguisher or fire hose. As the only characterizer presented in the model, time was set for the alternative "break the door". It means that time is an important aspect to be considered when analysing the actions of breaking the door. The implications defined related only to the first proposed alternative (Door Break): panic by the victims trying to leave the building, broken glass, and the fire's spread. The first implication was defined by the group as having a high impact, as well as the third. The second was defined as low impact. The impact model developed by Group I had a projection with less detailing. This result is in conformity with the group interaction divergences.

Group II worked from the perspective of two scenarios: fire in the lobby and fire in a room with people inside. For the first scenario, the alternatives considered were: go to the back door; search for windows in the building that facilitate the people's evacuation; use the second-floor exit; and take people out of their rooms to facilitate evacuation. For the second scenario: try to put out the fire from the door and Try to remove people through the window. During the study, Group II defined 12 implications, informing their impact metric to support the average calculation.

Group III worked with only one scenario (fire inside the building) that was associated with four alternatives: assess fire, identify origin, identify possible escape routes, and alert people present in the building. The group also defined implications for each alternative and reported the metrics for each of them. The result achieved by this group show that they did not consider the scenario constructs in the impact projection and it resulted in less instances of alternatives and implications. This shows that the good relationship between the participants in the group is not decisive for a satisfactory impact projection. In addition, there were indications that changing the systematization presented beyond the impact model can result in a worse impact projection.

Group V acted in the same way as the previous groups in setting the scenarios. They defined the scenarios according to the focus location of the fire in the building. Group V defined: fire in the upper part of the building, fire in the central part of the building, and fire in the lower part of the building. Although the group was able to define the scenarios, alternatives, implications, characterizers and metrics, it failed to make explicit in the model the relationships between them. Group V had difficulty in constructing the model, and the interaction difficulties and the group's lack of experience in decision-making processes may be the reason for that.

Group IV, unlike the other groups, constructed their scenarios based on the fire's intensity: intense fire with many people, intense fire with few people, and low fire. This group defined alternatives with greater richness of detail, such as: notify the occupants of the building about the danger without being put at risk; organize the flow of people in places of great concentration; explore the building to rescue people; and try to put out the fire. This group, although less experienced in decision processes, showed a balanced performance in their interactions, which reflected in the representation of impacts projection. The group concluded with the construction of the impact model, informing the weights for the impact metric calculation. The result of the model constructed by Group IV showed that a balanced group, with little experience in the decision-making process, is capable of projecting the impact of a complex decision based on a model that guides it in this task.

Another analysis can be done considering the number of participants in each group. Table 3 shows that the group with more participants (Group I) built quantitatively poor models, while small groups (Group II and Group III) achieved an impact model with more details, as well as the inexperienced teams (Group IV and Group V). In this analysis we must consider the fact that huge groups composed of experienced decision-makers did not have significant results. We believe this happened because the participants'

personal characteristics influenced the dynamic of this study, as discussed in the beginning of this section. On the other hand, small groups managed to establish a good interaction between peers, but the experienced teams delivered better results.

The pre-existing relationship between the decision-makers in a group can also be analysed. Groups I and II had one participant that never worked with the other participants before. However, Table 3 shows that Group II has a detailed impact model, and Group I did not have the same approach. At this point, the influence of decision-maker's approximation level with the other participants is inconclusive.

As was presented and discussed in this section, the impact models (impact projection structure and value attributed to each alternative structure—Fig. 6a, b) developed by the participants were considered complete when the group applied all the constructs foreseen in this research, keeping the systematization proposed in this research. The more detailed the impact structures developed (impact model—Fig. 6), the more resources are available for decision-makers to select the satisfactory decision path to be applied. The next section presents the discussion of the results according to the study observation, the form answers, and the artefacts produced (structures described in this section) by the participants.

3.3 Decision groups acceptance

In order to collect the participants' impressions, their satisfaction degree with the proposal and possible improvements, a form was developed with open- and close-ended questions about the study. Each participant answered the form using his personal experience about the study. It lasted a maximum of 8 min.

On an 11-point scale ranging from zero (unlikely) to ten (most likely), 88% of participants marked 5 as the probability of recommending the impact projection model to a decision group. For the recommendation of the impact model, 46% of these 88% marked 8 as a probability. All 17 participants stated, in different degrees, that they would use the impact model again as a support for projection and analysis of complex decisions. Considering the data collected by the form, one aspect to be highlighted is that the groups composed of participants who were more experienced in the decision-making process presented a lower recommendation index of the model, when compared to the trainee level participants. According to the participants, the most experienced decision-makers stated that they knew little about the potentialities of the impact model, since this was their first contact with the projection model. One respondent said, "I do not have a vast knowledge about the impact projection model. That keeps

me from evaluating it more accurately." Even those who assigned a grade above 8 for the recommendation stated that the model needs to evolve to further facilitate the decision group's discussion. One participant reported that, "In the final stage of impact projection (including metrics), I think the model does not add great utility to people with experience and mastery of the analysis environment." This shows that, in his view, the calculation of the average impact did not add much to the impact projection. In complex decisions, fostering discussion and analysis of the decision is more important than the choice of the alternative, due to the decision characteristics.

According to the respondents, more than 88% said they were satisfied with the impact model. As a justification for the participants' satisfaction, we have: "I was able to establish the discussions about the decision," and "The built model had a more general picture; it sought to look at the macro scale of the proposed event."

The positive aspect of this result for the proposed model is that no participant was defined as dissatisfied with the results achieved in the study; they only offered improvements for the proposal. For the participants who remained neutral regarding their satisfaction, they pointed out that: "The time available for the task was insufficient to complete the construction of the model," "I do not know if I understand the proposal, but it was not clear for me how it supports my good choices," and "As a first experience, I took time to familiarize myself with the scenarios and decisions relevant to the problem described." The neutral position is justified by the participants considering the model's in-depth knowledge, and how to perform good choices. However, the main goal of this research is not to support the complex decision-making of good choices, but rather the decision analyses and the impact projection. Concerning the proposal learning, it is natural for it to take time to learn a new method and its artefacts.

Regarding the quality of the projection obtained through the impact model, more than 58% of the respondents rated it as high quality. More than 94% of the respondents believed that the impact model is capable of aiding decision analysis by the decision group. The participants said, "I consider that the model supports the ideas organization and group interaction. The model can be useful as a starting point for impact projection," and "The possibility of discussing the actions implications in the form of impacts is relevant, especially when people from different profiles can contribute to the construction," and "it will be a differential in meetings with large group and/or remote meeting members."

The participants highlighted the positive and negative aspects of their experience in the analysis and impacts projection of complex decisions through the impact model. As a positive observation, even the impact model

Table 4 Consolidation of the improvements raised in the study

ID	Improvement	Impact model	Process	New solution
1	Adaptive tool for collaborative construction of the impact projection model			X
2	Introducing a moderator in workgroups		X	
3	Include some experienced decision-maker in the working group		X	
4	Disregard the general metric on projected impact	X	X	
5	Define fixed characterizers for the analysis of decision alternatives.	X	X	
6	Construction of a technological tool			X

and the process were novel to the participants, they were not difficult to learn as the following report confirms: “Even with the group unaccustomed to the model structure, after we began we understand it better and the utility [*the current use*] of the model became quick and easy.” In addition, the proposal enabled an interaction between the participants in a clear and unrestricted way: “The experience [projection construction] allowed discussion without limitations. The group can freely think and rethink the theme without having to fit into complex predefined structures. It is very close to modelling a conceptual/mental map, but with the differential of bringing very flexible auxiliary structures.” As a negative aspect, the respondents highlighted the confrontation of a new and unknown universe in detail which is the proposed impact model and the method represented by the Impact projection orientation process. According to them, to extract value from the experience of use, it is necessary to fully understand the specificities of each element that composes this proposal. Otherwise, impact projections are presented in shallow depth.

In the respondents’ view, “the scalable way, in which solutions are addressed, starting with the scenario definition, deriving after to alternatives, and then to implications” is the main facilitator proposed by the impact model. Besides this, the construction of a propitious environment to the discussions between decision-makers favours the projections definition still in the planning phase of the process.

By analysing the answers and justifications of the respondents, it is possible to find aspects to be improved in the proposal. Three respondents said they felt the need for different versions of the impact model to meet different decision needs. For them, “the model could adjust to different situations and become an adaptive tool that would effectively support the decision-making process.” Two of these three, introduced a new relationship between the constructs of the proposed impact model. They needed to incorporate cyclical relationships. This means that an implication can generate new decision questions for analysis and impacts by the group. Besides that, they discussed the alternatives in a draft, out of the impact model.

Approximately 47% of the respondents said they felt the need for a moderator in the group. For them, the presence of a decision-maker with this role would facilitate interaction in the group and, consequently, the performance of the collaborative tasks of projection of impacts. The participants stressed that the experience of decision-makers in similar situations improved the execution of the impact’s projection.

The totality of the participants (specialists) reported they felt less cognitively overloaded, once they had been oriented on how to perform tasks related to complex decisions. This result shows the participants feelings and opens a way to investigate this aspect further.

About 82% of respondents said they saw no meaning in establishing a general metric for impact. The average established is not significant. In the participants’ view, the relevance of the proposal is to establish an environment that supports: (1) the understanding of a complex decision, (2) the collaborative interaction between the decision-makers involved, and (3) the indication of tasks that need to be fulfilled to project the possible impacts of an action taken. Improvements on the element characterizer were cited by respondents. For one of them, this element should be fixed to facilitate the tasks detailing the focus on the impact’s projection.

Finally, all the participants stated that a technological tool would facilitate the process of analysis and collaborative projection of the complex decisions’ impacts. The most significant justifications for the respondents were expressed in the following comments: “With a tool that implements the proposed impact model, I imagine that the group decision-making process or a non-face-to-face meeting, will be simpler and more visual,” “With the use of a tool it would be easier to create and store models, thinking about their reuse,” “The tool would allow the specialists’ participation from the most diverse areas related to the scenario under analysis, with significant cost reduction,” and, “Whether it is necessary to work remotely would certainly make it easier. In that case, to be useful, I think the tool has to be interactive.”

The observation research technique goals were achieved too. Table 3 shows that all constructs of impact

model were applied. Section 3.2 discusses the impact model development by the participants teams. This discussion with the results commented in Sect. 3.3 shows that the sequence of the impact projection make sense for the participants. The discussion in Sects. 3.2 and 3.3 provides evidence that the process (Fig. 9) orients the impact projection because the main activities were performed, and the teams achieve an acceptable interaction protocol, even with the difference in personality.

Table 4 shows the improvements consolidation cited by the participants and their correlation with the products impacted by this research proposal or with possible new products to be included in the proposed framework. Given the results achieved, it is possible to affirm that the pre-defined goals were met. All participating specialists recommend the model for new impact projections. Through the results, the impact model structure supported the collaboration establishment between decision-makers, the decision analyses and the impact projection. It was also observed that the impact model is connected to the decision group orientation process, considering the phases performed throughout this study and the collaborative impact projection tasks previously discussed in Sect. 2.

4 Conclusion

The current work proposed a solution for supporting decision-makers, before the decision execution, the projection of complex decision impact while it is still in the planning phase of the decision process. As it was discussed, this solution represents a collaborative approach, which supports decision-makers in sharing their experiences and knowledge to obtain a common ground for performing their related decision tasks in order to analyse and project complex decision impacts. As such, the Conceptual Framework to Projected Complex Decisions Impacts (PICD) was developed. This framework, together with the specialists' necessity, gave the necessary structure to support the development of the Impact Model and the Projected Impact Orientation Process. Both, model and process are related. The process role determines how the model must be constructed by the decision group. Besides that, this solution involves: (1) using a shared workspace that can be virtual or real; (2) establishing a decision group discussion by a protocol to support the complex decision analysis and project its impacts; (3) development by the decision team a collaborative impact model, sharing and developing decision group knowledge related to the complex decision.

This solution was evaluated, as defined in the research methodological structure (Fig. 1). In this study, five decision-makers group participated. These participants have

different levels of experiences with the decision process. It is possible to affirm that the pre-defined goals were met. The impact model was proven to have the potential to be applied by decision groups to the impact projection of complex decisions—since all participating decision-makers recommend the model for new projections. Through the results, it was also confirmed that the impact model and its knowledge structure support the establishment of collaboration between decision-makers. It was also observed that the impact model adhered to the orientation process of the decision group.

The results showed a systematizing structure to project impacts of complex decisions before the decision execution, considering discussion, decision analyses and impact projection. It was observed that the knowledge and experiences of decision-makers participants were collaboratively improved to support the decision question. For future work, we are planning another study with a control group to achieve realistic results and a study to investigate the applicability of the decision impact data base in a run time decision to support decision-makers activities.

During the studies, the participants highlighted the necessity of a technological tool to support the decision analyses impacts definitions without the obligation for having the decision group meeting in person. In a near future, we would like to investigate and design a dynamic and technological environment to help decision groups to collaborate during their impact projection tasks, considering as premise the results achieved by this research.

This research opens a path to explore how decision-makers' personal characteristics influence the performance of complex decision impact projections. The discussions presented in Sect. 3.2 show that shyness and insecurity are examples of characteristics that can change the impact projection results. However, it demands more investigation and a solid base to be affirmed.

At the end of this paper, we understand that a formal representation of the conceptual structure can be improved. An ontology can be used to develop this new representation. The PICD framework was composed of a conceptual structure (Figs. 4, 5) that plays the role of a fundamental the impact model. To be more precise about the complex decision (concerned to naturalistic decision-making theory) scope and the absorption of its concepts in the impact model structure and the process proposed (Figs. 6, 9), we believe that an unambiguous model can improve the PICD framework and, consequently, the artefacts related.

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References

- Geisler M, Allwood CM (2018) Relating decision-making styles to social orientation and time approach. *J Behav Decis Mak* 31:415–429
- Karakul M, Qudrat-Ullah H (2008) How to improve dynamic decision making? practice and promise. In: Qudrat-Ullah H, Spector JM, Davidsen PI (eds) *Complex decision making. Theory and Practice*, Cambridge, pp 3–24
- Pereira ACTD, Santoro FM (2010) Cognitive decision making process as context information. In: *The 15th IFIP WG8.3 international conference on decision support systems, Lisboa. Proceedings of the 15th IFIP WG8.3 international conference on decision support systems*
- Sterman JD (1989) Misperceptions of feedback in dynamic decision making. *Organ Behav Hum Decis Process* 43:301–335
- Hutchins S, Kendall T (2011) The role of cognition in team collaboration during complex problem solving. In: Mosier KL, Fisher UM (eds) *Informed by knowledge expert performance in complex situations*. Psychology Press, Taylor & Francis Group, East Sussex, pp 69–90
- Yang L, Xu Y (2010) Decision making with uncertainty information based on lattice-valued fuzzy concept lattice. *J Univ Comput Sci* 16(1):159–177
- Doyle JK, Radzicki MJ, Trees WS (2008) Measuring change in mental models of complex dynamic systems. In: Qudrat-Ullah H, Spector JM, Davidsen PI (eds) *Complex decision making. Theory and Practice*, Cambridge, pp 269–294
- Gore J, Ward P, Conway GE, Ormerod BL, Wong W, Stanton NA (2018) Naturalistic decision making: navigating uncertainty in complex sociotechnical work. *Cogn Tech Work* 20:521. <https://doi.org/10.1007/s10111-018-0531-x>
- Klein GA, Klinger D (1991) Naturalistic decision making. *Hum Syst* 9(3):456–460
- Orasanu J, Connolly T (1993) The reinvention of decision making. In: Klein GA, Orasanu J, Calderwood R, Zsombok E (eds) *Decision making in action: models and methods*. Ablex Publishing Corporation Norwood, New Jersey, pp 3–20
- Klein GA, Orasanu J, Calderwood R, Zsombok E (1993) *Decision making in action: models and methods*. Ablex Publishing Corporation Norwood, New Jersey, pp 138–147
- Hammond JS, Keeney RL, Raiffa H (2002) *Smart choices: a practical guide to making better life decisions*. Broadway Books, New York
- Aldea A, Bañares-Alcántara R, Skrzypczak S (2012) Managing information to support the decision-making process. *J Inf Knowl Manag* 11(3):1250016
- Hunt JD, Bañares-Alcántara R, Hanbury D (2013) A new integrated tool for complex decision making: application to the UK energy sector. *Decis Support Syst* 54(1427):1441
- Jenkins DP, Stanton NA, Salmon PM, Walker GH, Rafferty LA (2010) Using the decision ladder to add a formative element to naturalistic decision-making research. *Int J Hum Comput Interact* 26(2):132–146
- Shattuck LG, Miller NL (2006) Extending naturalistic decision making to complex organizations: a dynamic model of situated cognition. *Organization Studies*, Warsaw, pp 989–1009
- Leifler O, Eriksson H (2012) Analysis tools in the study of distributed decision-making: a meta-study of command and control research. *Cogn Tech Work* 14:157. <https://doi.org/10.1007/s10111-011-0177-4>
- Neumann W (2017) *Team learning at work. activities, products, and antecedents of team learning in organizational complex decision-making teams*. Doctoral Thesis, Regensburg University
- Camarinha-Matos LM, Abreu A (2007) Performance indicators for collaborative networks based on collaboration benefits. *Prod Plan Control* 18(7):592–609. <https://doi.org/10.1080/09537280701546880>
- Camarinha-Matos LM, Afsarmanesh H (2018) Roots of collaboration: nature-inspired solutions for collaborative networks. *IEEE Access* 6:30829–30843. <https://doi.org/10.1109/access.2018.2845119>
- Guerrini FM, Yamanari JS (2019) A systematic review of collaborative networks: implications for sensing, smart and sustainable enterprises. In: Camarinha-Matos L, Afsarmanesh H, Antonelli D (eds) *Collaborative networks and digital transformation. PRO-VE 2019. IFIP advances in information and communication technology*, vol 568. Springer, Cham
- Laal M, Ghodsi SM (2012) Benefits of collaborative learning. *Procedia Soc Behav Sci* 31:486–490
- Austin JE (2000) Principles for partnership. *J Lead* 18(Fall):44–50
- Leonard PE, Leonard LJ (2001) The c*collaborative prescription: remedy or reverie? *Int J Leadersh Educ* 4(4):383–399
- França JBS, Neiva FW, Dias AFS, Borges MRS (2017) Towards the characterization of impact projection for complex. In: *IEEE international conference on systems, man, and cybernetics, Banff. IEEE International conference on systems, man, and cybernetics, V1*. <https://ieeexplore.ieee.org/document/8123003/>
- Diirr B, Borges MRS (2016) Shaping procedures to deal with complex situations. In: *IEEE international conference on systems, man, and cybernetics, 2016, Budapest. Proceedings of IEEE international conference on systems, man, and cybernetics*
- Cordeiro KF (2015) aDApTA: Adaptive approach for information integration to support decision making in complex environments. Post-Graduation Program in informatics, Mathematics Institute, Tércio Pacitti Institute of applications and Computational Research. Federal University of Rio de Janeiro, Rio de Janeiro
- Harris D, Li W (2016) *Decision making in aviation*. Routledge, New York
- Santos RS, Borges MR, Canós JH, Gomes JO (2011) The assessment of information technology maturity in emergency response organizations. *Group Decis Negot* 20:593–613
- Keys DJ, Schwartz B (2007) “Leaky” rationality: how research on behavioral decision making challenges normative standards of rationality. *Perspect Psychol Sci* 2:162–180. <https://doi.org/10.1111/j.1745-6916.2007.00035.x>
- Qudrat-Ullah H (2015) *Better decision making in complex, dynamic tasks. Training with Human-Facilitated. Interactive Learning Environments*. School of Administrative Studies, York University, Toronto
- Mosier K, Fisher U, Hoffman RR, Klein G (2018) Expert professional judgments and “naturalistic decision making”. In: Ericsson KA, Hoffman RR, Kozbelt A, Williams AM (eds) *The Cambridge handbook of expertise and expert performance*. Cambridge University Press, Cambridge, pp 453–475

33. Ayyub BM (2014) Risk analysis in engineering and economics, 2nd edn. Chapman & Hall/CRC, London. ISBN 1-58488-395-2
34. Araujo FCS, Borges MRS (2012) Support for systems development in mobile devices used in emergency management. In: CSCWD 2012—IEEE international conference on computer supported cooperative work in design 1, 2012, wuhan. proceedings ... IEEE Computer Press, Los Alamitos, USA
35. França JBS, Neiva FW, Dias AFS, Borges MRS (2017) Towards projected impacts on emergency domains through a conceptual framework. In: International conference on information systems for crisis response and management, Albi, France. XIV international conference on information systems for crisis response and management. http://idl.iscram.org/files/julianabsfranca/2017/1467_JulianaB.S.Franca_etal2017.pdf
36. Nutt PC, Wilson DC (eds) (2010) Handbook of decision making. Wiley, West Sussex
37. Mattos TC, Santoro FM, Revoredo K, Nunes VT (2014) A formal representation for context-aware business processes. *Comput Ind* 65:1193–1214
38. Vieira V (2008) CEManTIKA: a domain-independent framework for designing context-sensitive system. Doctoral thesis. Federal University of Pernambuco
39. Oliveira FF (2009) Ontology collaboration and its applications. M.Sc. dissertation. Post-graduation Program in Informatics, Federal University of Espírito Santo, Vitória, Brazil (in Portuguese)
40. Foshay R, Kirkley J (2003) Principles for teaching problem solving. Technical Paper (No. PLATO-TP-4). U.S. Minnesota
41. Klimoski R (1994) Team mental model: construct or metaphor? *J Manag* 20(2):403–437. [https://doi.org/10.1016/0149-2063\(94\)90021-3](https://doi.org/10.1016/0149-2063(94)90021-3)

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