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On the Complementarity between CMMN and iStar in Complex Domain Modeling

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Abstract. Case Management Modeling and Notation (CMMN) and iStar are two distinct, multi-purposed modeling techniques that may be used to represent organizational challenges at separate levels of abstraction. CMMN, a flexible process-oriented technique, aims to extract knowledge that enhances the representational capacity of activity flows for a specific case. Conversely, the iStar framework adopts a goal-oriented modeling approach, effectively capturing the interplay of social actors and their influence on the attainment of organizational objectives. While prior studies have explored methods for integrating these techniques to attain a more comprehensive understanding of the organizational landscape, these remain primarily associated with a distinct level of the organizational matrix (i.e., CMMN for operations and tactics, and iStar for more strategic aspects). As such, any effort to evaluate their semantic proximity appears fragmented, as it deals only with the partial association of specific notations and elements. This article describes the conduct of a dual-purposed literature review to identify specific criteria that might accommodate a more holistic assessment of the two modeling techniques; these criteria are then employed as a guiding framework to construct a set of propositions that articulate the areas of complementarity and/or divergence between these two techniques, as identified in previous research. These propositions are subsequently subjected to validation by domain experts, leveraging a real-world case study in the educational domain. The results show that there can be areas of semantic convergence between the two techniques, suggesting their parallel use to effectively model complex domain problems. Overall, the present study aims to crystallize an approach for conducting complex modeling comparisons that transcends technical considerations.

Keywords: Case Management Modeling Notation, CMMN, iStar, Social Modeling, Semantic Complementarity, Interoperability of Modeling Techniques.

1 Introduction

Contemporary organizations depend on the establishment of well-defined business processes to streamline operations, deliver superior services, and develop information systems that enhance in-

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ternal decision-making mechanisms [1]. However, the retrieval of highly repetitive, standardized, and predictable activities in order to establish and subsequently optimize a business process can prove to be quite challenging in practice [2]. Furthermore, in certain cases, the incorporation of flexibility into decision-making and the dissemination of knowledge derived from a particular process may prove more critical for the achievement of organizational objectives than the design of rigid workflows [3], [4], [5]. In this regard, Case Management Modeling and Notation (CMMN) [6] is an example of a declarative[1], process-oriented, modeling language enabling the use of a gamut of notations and design elements to support a flexible process management approach suitable for knowledge-intensive cases. In contrast to prescriptive process-centric techniques like Business Process Modeling and Notation (BPMN) [8], CMMN prioritizes formalizing the core functionalities of a specific case or domain problem while avoiding the upfront definition of a rigid process flow. The provision of this type of flexibility makes CMMN particularly well-suited for modeling high-level processes that require adaptability [7], [9], [10].

Nevertheless, a holistic representation of a specific case or domain problem often requires more than the use of high-level activity streams that describe the way to achieve functional objectives. Indeed, some additional information about the social context that permeates the problem and the interplay of actors that participate in the shaping process of these objectives can be rather beneficial. In that aspect, the iStar framework [11] provides modeling elements targeted at identifying dependencies and highlights the rationale of actors in complex socio-technical environments. The iStar framework has often been employed in software development [12], but its applications have expanded to a broader business context in recent years. For instance, the framework has proven effective in analyzing the strategic impact of technology adoption at both the organizational-, and country-levels (for instance, the studies of Tsilionis & Wautelet [13], [14], and Heng et al. [15]).

There are studies exploring methods to integrate various process modeling notations and social modeling techniques (for instance, the studies of Estrada et al. [16], and Sousa & do Prado Leite [17]). However, such studies often allocate each technique to distinct levels within the organization, with process modeling representing operational and tactical-level activities, and social modeling techniques representing the state of interplay among various stakeholders that influence the attainment of strategic objectives. There are even studies that have tried to establish conceptual linkages between these modeling techniques (for instance, the studies of Eshuis & Ghose [18], Lunn et al. [19], and Wautelet & Poelmans [20]). However, such studies often adopt an empirical approach that neglects the articulation of a set of objective comparison criteria that would allow a deeper understanding of the potential semantic interlock between such techniques.

The present article examines the prospect of complementarity between the CMMN modeling technique and the iStar framework. CMMN was chosen as a champion of a flexible, procedural modeling technique able to depict a collection of loosely coupled units of *tasks* for the description of a specific case. The iStar framework, on the other hand, was chosen as one of the most cited goal-oriented modeling frameworks, having the capacity to clasp actors (and their goals) to such *tasks*. The article begins by exploring the process of retrieving some criteria that form the basis for assessing the modeling congruence between the two techniques. These criteria are the outcome of the conduct of a literature review. Next, the literature is reviewed again to collect relevant contextual propositions that evaluate these techniques according to the aforementioned criteria. The veracity of these propositions is thereafter validated by domain experts on the basis of a case study conducted within the educational domain. It is noteworthy that the present article is not meant to compare the technical performance of these two techniques; we are more concerned with uncovering areas of synergies in the modeling intentions for these two techniques when studying a particular domain problem. And since experienced software modelers may exhibit a bias towards the use of one particular modeling technique over the other, we have decided to recruit domain

[1] The term is used here to describe a process method focusing on describing “what” can be achieved and not “how” a result can be achieved [7].

experts, as they are more likely to be objective in their assessment of the two modeling techniques. As such, the research question for the present study can be defined as follows: *How can the complementarity of Adaptive Process-Centric (CMMN) and Social-Oriented (iStar framework) Modeling Techniques enhance the semantic representation and analysis of complex domain problems?*

The article is structured as follows: Section 2 is meant to provide a high-level description of CMMN and iStar, as well as explain their main syntax elements. Section 3 presents the related works in terms of establishing a primary introspection of the aforementioned techniques. Section 4 describes the research methodology by detailing the conduct of a dual-purposed literature review to (i) establish a set of evaluation criteria, and (ii) derive a set of propositions determining the state-of-the-art for CMMN and iStar. The case study which is used to evaluate these propositions is also described. Section 5 presents some results as the outcome of this evaluation. Sections 6 and 7 present a discussion of these results and some limitations respectively. Section 8 concludes the article.

2 Exploring the Key Components of CMMN and iStar

This section provides an overview of CMMN and iStar as contemporary modeling approaches. CMMN, developed by the Object Management Group (OMG) [21], is a declarative modeling notation addressing the need for standardized representation of knowledge-intensive organizational processes requiring flexibility during modeling [22]. With organizations facing loosely-structured processes demanding ad-hoc decision-making, CMMN offers modeling elements to describe them effectively [9], [10]. It allows managing internal cases and associated activities within organizations without defining a process a priori. Notable advantages of using CMMN include surpassing rigid workflow constraints, supporting characteristic generalization, and increasing user flexibility during process execution [23], [9].

Overall, CMMN can be used in dynamic, data-driven, task-oriented situations where the input of knowledge workers[2] is largely needed to achieve an organisational outcome [2]. Given that knowledge workers represent the greatest value contributor in service-oriented economies [24], CMMN is gaining all the more relevance as a modelling technique. Knowledge work involves critical, complex and analytic thinking, expertise, and flexibility that can produce rapid responses to unexpected situations. These kinds of situations request the adaptation of the case during runtime by the knowledge worker, making the subject of the knowledge work manageable [25]. Typical examples of knowledge work include a gynecologist performing a cesarean section, an attorney developing their client's court defence, a marketing analyst organising an advertisement campaign, or an IT professional fixing a web portal that has crashed [26], [27]. The common denominator of all of these examples is that they refer to cases where professionals do not follow a rigidly standardised procedure to perform their work; rather, they tend to rely on their experience to reach a specific result. Some basic modeling elements incorporated in CMMN diagrams are described below. Given space constraints, the reader can find the visualization of the below elements in Figure 1 in Section 5.1:

- Stages: They depict episodes within a particular case and can be categorized as either 'expanded' or 'collapsed' depending on the level of detail needed to describe the case. Stages may also be classified as 'ordinary' or 'discretionary' based on the volition of their nature.
- Tasks: They represent activities that need to be performed within the organization. Same as stages, they can also be 'ordinary' or 'discretionary' and further classified into non-blocking human tasks, blocking human tasks, case tasks, process tasks, and decision tasks.
- Sentries: They combine events and conditions to determine when stages, tasks, or milestones should be activated or terminated. They can take the form of entry criteria or exit criteria, depending on whether they initiate or terminate a case plan model.

[2] Knowledge workers refer to specific organizational roles possessing significant domain experience.

- Events: They signify business-related occurrences within a case. They are categorized as either timer-event listeners or user-event listeners, representing time-lapse or user interactions, respectively.
- Milestones: They represent targets to be achieved upon the successful completion of tasks, signifying progress within the case.
- Planning Tables: They are used to manage discretionary items within stages, human tasks, or case plan models, indicating when these items are visible or hidden.
- Decorators: They are attributes that indicate specific types of behaviors or characteristics associated with elements within a case model. They are optional and serve to add more context in the case or task. They are used to classify such elements as auto-complete, required, repetitive, and manually activated.

On the other hand, the iStar framework refers to a social modeling language purposed to elucidate the socio-technical structure of organizational environments. In iStar, organizational stakeholders are depicted as actors reliant on each other to achieve goals, execute tasks, with the ultimate goal of utilizing, sharing, and efficiently redistributing resources among each other [28]. In iStar, the actions of actors are bound by elements of autonomy and intentionality in the effort to build interdependent relationships; as such, the framework provides a modeling approach that is purposed to yield insights into the social dimension of environments [28], [29]. With increasing emphasis on goal specification in social contexts, the use of iStar finds applicability in diverse business domains such as requirements engineering, domain understanding, and organizational modeling [30], [31], [32].

Overall, the framework encompasses the Strategic Dependency model (SD) and the Strategic Rationale model (SR). The elements of those models are fully described in the study of Yu [28]. For the purposes of this article, we shortly describe that the SD model illustrates dependency relationships among actors (i.e., showing who depends on whom within an organizational context). It consists of nodes representing actors and links denoting dependencies between them, with the depending actor termed *Depender* and the depended-upon actor called the *Dependee* [28], [33]. Contrastingly, the SR model offers an intentional depiction of processes in the effort to support their explainability and rationale. Unlike the SD model, the SR model delves deeper into actors' reasoning by explicitly expressing their internal relationships; the ultimate goal is to describe the *why* and *how* of processes so organizational modelers can better address actors' interests and concerns. The SR model is graph-based, comprising various node and link types to represent the rationale behind processes succinctly [33], [34]. A typical example justifying the use of iStar would be the effort to chart the entire network of actors, and their interdependencies, when (re)designing the service portfolio of a healthcare institution (for instance, [35]), or the effort to map the task-, and resource-dependencies among different roles within a Scrum team during a sprint cycle (for instance, [36]). Some basic modeling elements incorporated in iStar diagrams (they are fully visualized in Figure 2 in Section 5.1) are described below:

- Agents: They comprise a type of actor with physical characteristics like a human, or a department.
- Roles: They refer to behaviors by social actors within a given organisational context, like an accountant or a salesperson.
- Hard-Goals: They refer to identifiable objectives that an actor wants to achieve with their actions directed to the realisation of these state of affairs.
- Tasks: They represent activities actors wish to be performed.
- Soft-Goals: They refer to situations that an actor wants to achieve but whose successful realisation is open to subjective interpretation, given that the criteria for satisfaction are not really clear-cut.
- Resources: They refer to physical or abstract elements that an actor needs to possess or produce.

In iStar diagrams, intentional elements are linked together, forming interconnected structures. The fundamental links include:

- Refinements: They connect tasks and goals hierarchically and are categorised in two types: ”AND” refinements (requiring execution of all sub-elements) or ”Inclusive OR” refinements (requiring fulfillment of one or more sub-elements for the main element to be fulfilled.
- Needed-by links: They are used to connect a resource with a task, meaning that the resource is a prerequisite for the task to be executed.
- Qualifications: They connect qualities to the element to which they are supposed to pertain, namely a task, a goal, or a resource.
- Contributions: They describe how intentional elements affect the realisation of qualities.

3 Related Work

Eshuis & Ghose [18] investigated the association between goal-oriented and declarative case management models. In particular, they defined a “user-defined correspondence function” where milestones in a case management schema could be associated to higher-level goals. However, the approach was only intended to establish a consistent association between goals and milestones without establishing a set of criteria that would allow a broader investigation of any other task-related associations between the features of distinct models. Comparatively, Lunn et al. [19] developed an iterative approach to identify traceability links between the goals of individual stakeholders and loosely structured business process models. Their method starts by determining generic goals, proceeds by providing an abstract overview of the key business processes satisfying these goals, and then refines such process models by identifying primary and alternative workflows. This approach, however, narrowly confines goals to mere IT operationalizations, overlooking the intricate interplay among actors in shaping and defining these goals.

Furthermore, there are studies delving into a comprehensive characterization of either the CMMN or the iStar modeling notation. For instance, Zensen & Küster [37] conducted an extensive evaluation of CMMN by meticulously examining generic dimensions such as process structure, routing and control flow, communications and events, and data flow. This analysis resulted in the formulation of practical guidelines that aid in determining the appropriate process-oriented modeling notation that should be used depending on the use of a specific domain context. In contrast, Matulevičius & Heymans [38] and Pastor et al. [39] focused on in-depth examinations of iStar. The former study employed the semiotic quality framework [40] to compare iStar with the method for Knowledge Acquisition in Automated Specification (KAoS) [41] in terms of the quality of their respective models. The latter study conducted a feature-based evaluation of iStar, revealing its strengths in model expressiveness and domain applicability while also identifying areas for improvement in refinement, modularity, and scalability. However, these studies did not explore semantic cross-validation between modeling techniques, which could provide valuable insights into the suitability of different viewpoints for representing a given domain problem.

4 Research Methodology

To investigate the existence of a possible complementarity between CMMN and iStar, we have chosen to perform an exploratory study [42]. Given the lack of clear guidelines that could help us formulate a clear comparative analysis between the two techniques, we had to proceed in an empiristic manner by combining various knowledge acquisition and data extraction methods [43]. The reader will be most likely able to detect a deductive approach [44] where data was extracted from the performance of a dual-purposed literature review. The *first branch* of the literature review was meant to compile a list of sources that could help us formulate clear criteria that could be used for the evaluation of complementarity between the two modeling techniques. The *second branch* of the literature review was dedicated to the retrieval of studies engaging in a performance evaluation of either one of these two modeling techniques, according to the set of criteria that was extracted from the first branch; the outcomes of these studies were then epitomized in the form of a set of evaluating propositions. A case study was also performed as a means of collecting qualitative data to appraise those propositions. In that manner, we stay true to the deductive logic described in the study of Gilgun [45], which inscribes to (i) first look at the theory (i.e., by performing the first branch of the literature review in our case), (ii) then produce hypotheses from the theory (i.e., by compiling the propositions derived from the second branch of the literature review in our case), and (iii) then proceed to test such hypotheses (i.e., by using the case study as the means to assess these propositions in our case). The sections below will describe the aforementioned research strategies in more detail.

4.1 Literature Review to Establish the Evaluation Criteria and Propositions

To determine the criteria upon which we could base our comparative analysis for the two modeling techniques, a narrative literature survey [46] was performed. Narrative literature reviews are often used in cases where the literature corpus is primarily limited –as in our case– to gather evidence readily available to the researchers [47], [46]. Narrative literature reviews have been sometimes criticized for lacking objective search criteria, but their use can be justified when there are few studies on the topic at hand [48], [46]. The present study tries to address the aforementioned criticisms by establishing an objective search algorithm to accommodate the retrieval of studies that could help us establish the criteria for comparing the two modeling techniques. We relied on the guidelines of Brereton et al. [49] and Kitchenham et al. [50] to establish the particular search algorithm. We can indicatively mention the specification of inclusion criteria (i.e., the most important of which was to include studies addressing specifically the establishment of criteria to evaluate distinct software modeling techniques), and exclusion criteria (i.e., the most important of which was to exclude studies that did not satisfy certain quality prerequisites and studies written in a language other than English). We also mention the identification of key search terms by evoking the Population, Intervention, Comparison, Outcomes, and Study (PICOS) design framework [51]. These were: (“Adaptive Case Modeling” **OR** “ACM” **OR** “Business Process Management Notation” **OR** “BPMN” **OR** “Process Modeling”) **AND** (“Social-Modeling” **OR** “Agent-Based Modeling” **OR** “Systems Engineering Modeling”) **AND** (“Criteria”) **AND** (“Evaluation”) **AND** (“Comparison”) **AND** (“Strengths”) **OR** (“Weakness”).

Overall, only formal sources were reviewed for the identification of the evaluation criteria. Such sources consisted of published scientific articles and books and were derived from searches on Google Scholar, Web of Science, and Limo libis[3]. Only the first two pages of the returned results, per source, were consulted since, after the second page, the sources were negotiating topics not directly associated with the one at hand. One member of the research team investigated the output of the preliminary search of the sources by going through their titles and abstracts, and whenever a suitable source was located, it was added to the spool. A full-text reading of the sources in the spool was conducted by the researcher and a secondary snowball analysis [52] was performed by the same researcher in order to collect additional articles.

The final outcome of this review is the denomination of a handout from four different sources that relinquish a series of specific evaluation criteria. The limited number of final studies can be explained by the exiguous quantity of directly relevant studies identified during the launch of our initial search. The final sources were: (i) Sturm & Shehory [53], introducing a framework for the assessment of agent-oriented methodologies, (ii) Blackwell et al. [54], introducing a framework to evaluate the usability of notational systems by focusing on the cognitive implications of a designed

[3] Limo libis refers to KU Leuven’s search engine. For more information, please see: https://bib.kuleuven.be/english/collections-access-borrowing/what-is-limo

artifact, (iii) Kelemen at al. [55], suggesting specific process-related evaluation criteria, and (iv) Vingerhoets et al. [56], suggesting generic evaluation criteria for software modeling languages.

After retrieving the aforementioned sources, each member of the research team went through each source and created an individual list of the criteria that should be considered in terms of evaluating the CMMN and iStar. Each list was extensively discussed, and the denomination of a final list of 10 evaluation criteria was the result of a unanimous decision. These criteria are i) *Accessibility*, (ii) *Error-proneness*, and (iii) *Resource availability*, which refer to the generic quality characteristics of each modeling technique; there are also the criteria (iv) *Granularity*, (v) *Combinability*, (vi) *Modularity*, and (vii) *Scalability* which refer to the design attributes of each modeling technique; Last, there are the criteria (viii) *Domain Applicability*, (ix) *Workflow support*, and (x) *Social focus* which refer to the zones of application of each modeling technique. These criteria, as well as a detailed description of their evaluating dimensions, can be seen in Table 1 in Section 5.2.

The second branch of the literature review sought to identify academic sources that critically evaluate CMMN and/or iStar in light of the evaluation criteria established in the first branch. The search methodology was practically identical to the first branch, save for the minor adjustments that had to be made to accommodate the objectives of the second branch. For instance, different search strings had to be used such as: ("Case Management Modeling Notation" **OR** "CMMN" **OR** "CMMN Adaptive Process Management Notation" **OR** "CMMN Flexible Process Modeling") **AND** ("iStar Framework" **OR** "i* Framework" **OR** "i* Social-Modeling framework" **OR** "i* Agent-Based Modeling") **AND** ("Evaluation") **OR** ("Comparison") **AND** ("Quality Characteristics") **AND** ("Design Attributes") **AND** ("Application Domain"). A member of the research team performed the search queries and after having retrieved the final list of sources (see Table 1), thematic content analysis [57] was used to codify the insights from the literature review, following the paradigm of the studies of Gaur & Kumar [58] and Seuring & Gold [59]. Overall, each source from the final list was examined and the evaluation criteria were employed as the coding framework to nest the content of these sources into distinct categories. The process of analyzing and further codifying the insights unfolded across four iterations and was performed by each member of the research team individually. Our primary objective was to discern a convergence cluster within the sources, which could manifest as recurring phrases, patterns across the sources, or segments elucidating the distinctions between the two modeling techniques in light of our established criteria. This endeavor culminated in the formulation of 10 distinct propositions summarized in Table 1. These were evaluated by domain experts with the use of the case study described below.

4.2 Modeling MBA-Program Admissions: A Case Study in the Educational Domain

This section describes the case study used to assess the validity of the propositions outlined in Table 1. Yin [60] describes a case study as any kind of empirical inquiry meaning to investigate a specific phenomenon within a real-world context. In this vein, the case study presented here explores the capability of CMMN and iStar to capture the most critical elements of the admissions procedure for an elite MBA program offered by a prestigious university in Belgium[4]. The specific admissions case was chosen due to the substantial volume of admission files –compared to other programs– that must be processed within fixed time-frames (e.g., at the beginning of the academic year). This necessitates a knowledge-driven approach to the admissions case. In the context of this study, knowledge-driven implies that case handlers (i.e., admission officers) must utilize and manipulate a significant number of data points and knowledge elements (i.e., application files) to make informed decisions and guide the admissions process towards its desired end-state (i.e., evaluating and accepting or rejecting an applicant). The MBA admissions case can also be perceived as goal-oriented, as specific objectives must be achieved by the involved actors to ensure a successful

[4] The name of the university is left out of the study for privacy reasons.

outcome. Consequently, the described case is characterized by (i) a high degree of flexibility during run-time, which makes it suitable for using CMMN as a unit of analysis, and (ii) the presence of numerous intentional elements among various actors (i.e., program advisors, case handlers, applicants, etc.), which justifies the use of iStar as another unit of analysis. We employed these two distinct modeling techniques collectively to visually represent the MBA admissions exercise. The results of this implementation are presented in Section 5.1 in the form of a distinct CMMN diagram and an iStar Strategic Rationale Diagram (SRD) (see Figures 1 and 2). These diagrams served as the visual artifacts driving the comparative analysis of the propositions (see Table 1) as performed by specific domain experts. The process of accessing these domain experts is described next.

To capture information related to the MBA admissions case, we employed documentary analysis [61] as our primary data collection method. The latter refers to the collection of internal documents, educational policies, and formal procedures guiding the admission process; this task was performed by a member of the research team. The information gleaned from these documents enabled the research team to prepare an initial draft of the CMMN and iStar diagrams, representing the workflow and actors involved in the MBA admissions case. Following the completion of these diagrams, the research team organized an initial round of interviews in the form of a focus group, involving 3 admissions officers (domain experts) from the specific MBA program. The purpose of these interviews was to validate the accuracy of these models. The interview process unfolded as follows. We first acquired access to the university employee email directory (i.e., our sampling frame). Then we sent out an email invitation to all employees related to the MBA admissions case to explain the purpose and duration of the survey. Three professionals expressed interest and received a formal email invitation to participate in the survey, along with detailed information about the interview process, which would take the form of a group discussion. This discussion started with the interviewer (a member of the research team) making a comprehensive analysis of the characteristics of each modeling technique; then, a series of questions were posed to elicit information from the participants. The format and allocation of these questions were meant to (i) allow the domain experts to explain the admission case, and (ii) enable the experts to validate the information gathered through document analysis and scrutinize the first draft of the CMMN and iStar diagrams. Despite lacking software modeling experience, the domain experts were able to assess the initial draft of these diagrams to ensure an accurate representation of the admissions process. To reiterate, our objective was not to evaluate the techniques from a purely technical perspective. Instead, the aim of this study was to first establish evaluation criteria for the two modeling techniques and then use a specific domain problem as a platform to investigate their performance and potential areas of complementarity. In this context, the interviewees possessed significant workflow and domain expertise to evaluate the implementation of the two modeling techniques. In this vein, we followed the paradigm described in the study of Mohagheghi et al. [62] which involves domain experts to empirically establish best practices to facilitate the adoption of model-driven engineering techniques.

A second round of interviews was organized with the same domain experts in the form of a focus group. This time, the aim was to provide the experts with the opportunity to use CMMN and iStar as visual aids to evaluate the validity of the propositions gathered from the literature review. The interviews began with the interviewer presenting the evaluation criteria and propositions. Then, the participants were asked to review Figures 1 and 2 in order to evaluate each proposition mentioned in Table 1, expressing their agreement or disagreement with their content and validity. While the domain experts were unable to evaluate every proposition, they did assess those most relevant to the MBA admissions case. Upon completion of the second round of interviews, the subjects' answers were analyzed. Our goal was to systematically organize and codify the essential information from the interview data using the evaluation criteria of Table 1 as a thematic framework, and to efficiently extract insights from the respondents' perspectives regarding the complementarity between the two techniques. Consequently, we employed a combination of thematic content analysis and narrative synthesis [63] to analyze the interview data. This approach aligns with the study of Cruzes et al. [64], calling for the employment of multiple insight synthesis methods to enhance the reliability of results in software engineering studies using qualitative data. Accordingly, each member of the team perused the transcribed interview text multiple times to identify commonalities and/or points of differentiation in the respondents' answers. Commonalities would manifest as similar phrases used in different parts of the interviews, while divergences would manifest in the form of recurring differences between the focus group participants. We then tabulated the data to summarize the key insights, employing the structure of the evaluation criteria of Table 1 as the primary means of thematic codification for the responses. The results of the experts' assessments are presented at the end of Section 5.2.

5 Results

Section 5.1 showcases the application of CMMN and iStar techniques to address the specific domain problem (mapping the MBA admissions case under the guidance of insights derived from the interview process). Section 5.2 presents the compiled evaluation criteria in Table 1, which constitute one of the key contributions of this study; it also presents the literature-based propositions, which are structured around the contextual framework of these criteria, exemplifying another significant contribution of this work. This section culminates with the expert assessments associated with each proposition.

5.1 CMMN and iStar Diagrams for the MBA Admissions Case Study

Figure 1 describes the modeling result of the particular MBA admissions case with the use of the CMMN technique. In total, there are 4 stages that describe the MBA admissions case; these are the (i) *Check application file completion* stage, (ii) *Verifying document authenticity* stage, (iii) *Confirm the applicants eligibility* stage, and (iv) *Evaluate application* stage. All four stages are perceived as "expanded" (i.e., they include all case-related details) and "ordinary" (i.e., they include activities that occur necessarily).

The *Check application file completion* stage (first phase of the admissions process) consists of the non-blocking human task *Check files submitted*, a blocking human task called *Verify file completeness* and a discretionary blocking human task named *Request missing documents*. The first task is non-blocking since it can be performed completely manual and its performance does not interrupt the workflow, unlike the other two tasks requiring more time to complete. At this stage, it is possible to ask more documents from a potential applicant, thus the inclusion of the repetition decorator on the *Request missing documents* task. The entry criterion on the *Verify file completeness* task ensures that the incoming workflow is complete (i.e., the submitted files have been indeed checked). The *Required* decorator, marked as an exclamation point within the *Verify file completeness* task in Figure 1, marks the necessity to execute the particular task. Last, the exit criterion on the first expanded stage ensures that only when the application file has been checked, can the milestone *File Completeness Verified* be satisfied. The attainment of this milestone serves as the entry point for the *Verifying document authenticity* stage. Due to their similarity to the first stage, the structure of this stage and the *Confirm the applicants eligibility* stage will not be explained in detail here. The *Evaluate application* stage, which is triggered by the creation of the eligibility report, marks the last phase for the MBA admissions process. Here, the blocking human task *Read eligibility report* incorporates a manual activation decorator offering the case handler the choice to perform (or not perform) the task or perhaps postpone its execution to a later instance. For instance, when the program advisor receives multiple applications from students who graduated from the same university, he/she might choose not to consult more than once the eligibility report for that particular university. This last stage may result in the applicant's acceptance as a milestone, triggering the closure of the case. Contrastingly, the rejection of an application can occur at any

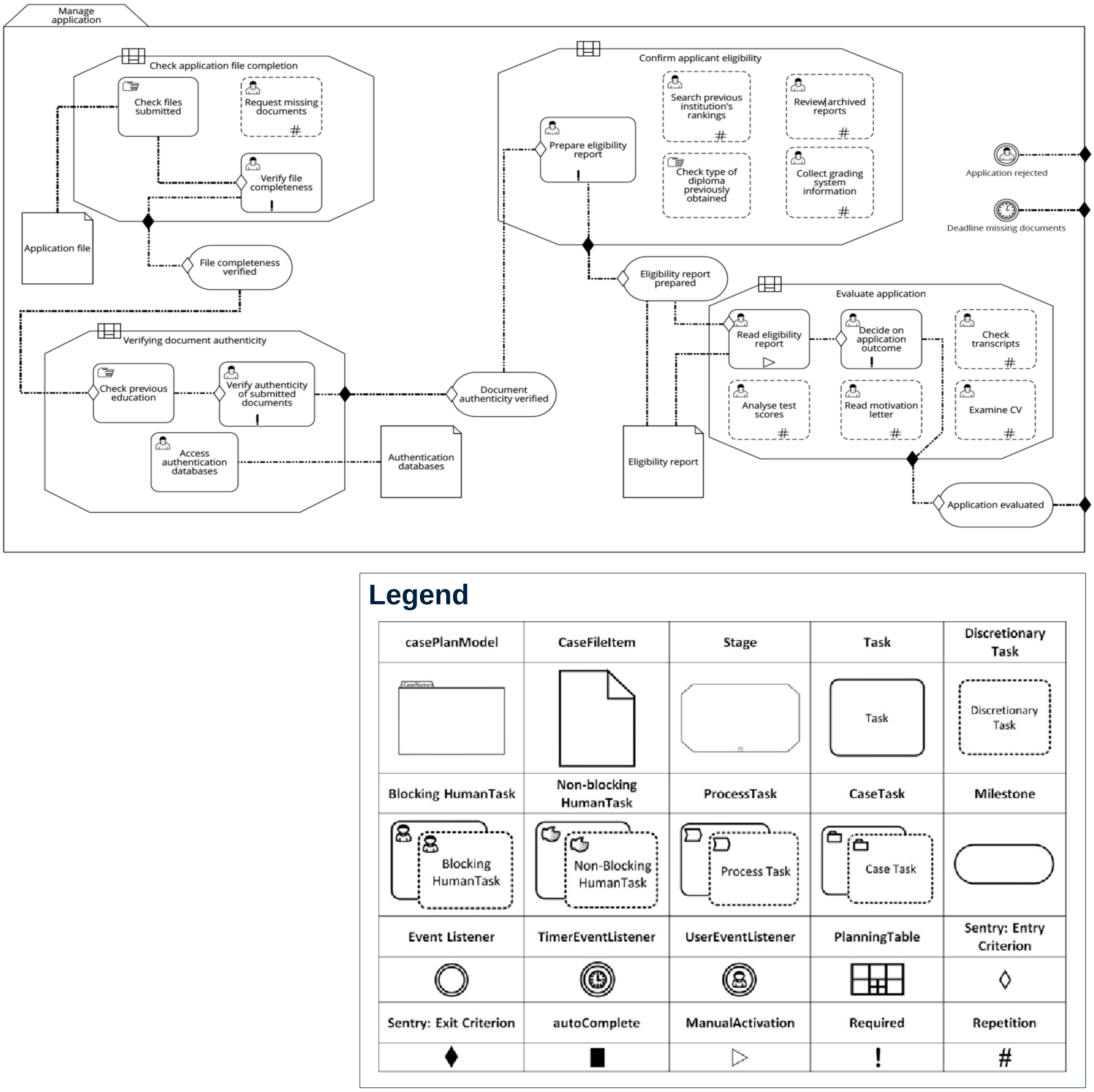

Figure 1. CMMN Diagram for MBA Admissions Case

given point within the four stages (e.g., when an applicant is deemed to be ineligible during the verification of the authenticity of his/her documents taking place in the second stage).

Figure 2 uses iStar to represent the main stakeholders participating in the particular MBA admissions case. These stakeholders are represented as (social) actors who depend on each other for goals to be achieved, tasks to be performed, and resources to be furnished [11]. For the sake of simplicity we do not go through a further exploration of the nature of these actors (i.e., actors in iStar can be further distinguished into 'roles', 'agents', etc.) since we are more interested in the nature of their dependencies. Due to space constraints, we opted to represent solely the iStar Strategic Rationale Diagram (SRD)[5] as it conceptualizes actor dependencies and enables the analysis of their decomposition. So, to begin with, Figure 2 illustrates the actors (i.e., *Applicant, Case administrator, Credential evaluator, Program advisor,* and *University*) involved in the MBA admission procedure, along with their existing interdependencies. These actors represent a spectrum of entities (i.e., human actor, organization, or department) engaging in a number of task-, goal-, and resource-dependencies with each other. For instance, the *Applicant* shares a hard-goal

[5] So the iStar Strategic Dependency Diagram (SDD) is not presently represented.

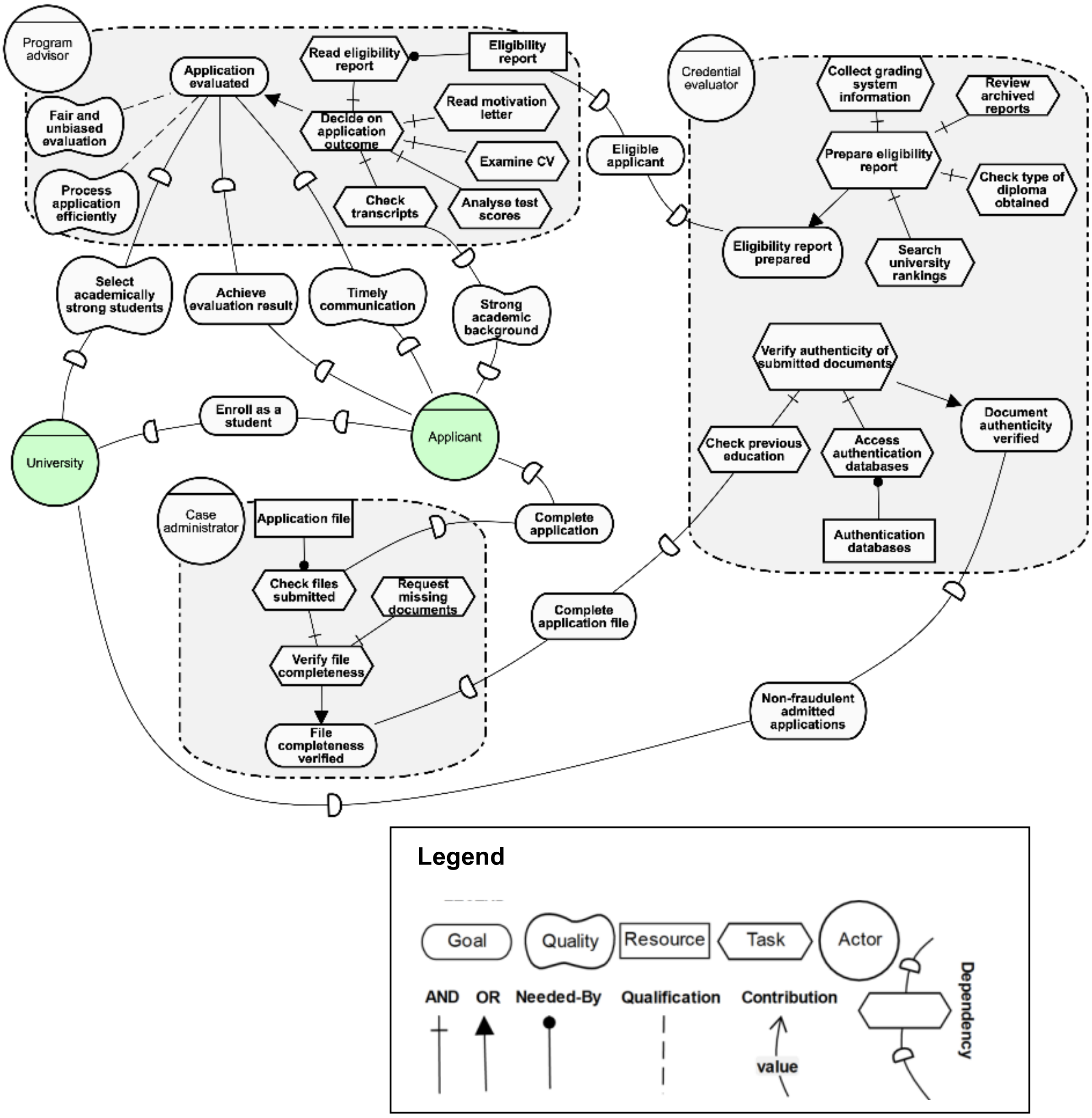

Figure 2. iStar Strategic Rationale Diagram for MBA Admissions Case

dependency with the *Program advisor*, with the former actor depending on the latter to *Achieve an evaluation result*; the last element represents a hard-goal because there are predetermined criteria set by university procedures to satisfy the achievement of that goal. However, the *Program advisor* also depends on the *Applicant* to be in possession of a *Strong academic background* in order to apply for admission. The latter represents a soft-goal dependency between these two actors since the nature of the strong academic background can be, more or less, open to interpretation according to the standards that the *University* actor sets (hence the existence of another dependency between the *Applicant* and the *University*). In Figure 2, the actors *University* and *Applicant* are cloistered and not thoroughly analyzed since the focus of the case study is on the representation of the admissions tasks from the perspective of the case handlers.

5.2 Evaluation Criteria, Propositions, and Experts Assessments

Table 1 presents the comprehensive framework that can be used to evaluate diverse software-related modeling techniques. This framework is comprised of 10, distinct, primary evaluation criteria such as *Accessibility*, *Error-proneness*, *Resource availability* (refering to the generic quality characteristics of each technique), *Granularity*, *Combinability*, *Modularity*, *Scalability* (refering to the design attributes of each technique), and *Domain applicability*, *Workflow support*, *Social focus* (refering to the zones of application of each technique). The second column provides a detailed description of each criterion, while the third column associates each criterion with the corresponding study from which it was derived (e.g., the study by Sturm & Shehory [53] describes how *Accessibility* can be used as a criterion to study distinct software modeling techniques). To reiterate, the propositions mentioned in Table 1 are derived from the second branch of the literature review (the studies used to derive each proposition can be found in the third column of Table 1), and they are the end result of the thematic content analysis process described in Section 4.1. These propositions are nested to their corresponding evaluation criteria.

The remaining of this section describes the domain experts' assessments on the propositions presented in Table 1. The experts' responses are based on the utilization of Figures 1 and 2 as visual aids, and are given below in the order of the presented evaluation criteria of Table 1.

Accessibility, Error-proneness, and Resource availability of CMMN and iStar. The domain experts considered the notations in the CMMN diagram rather intuitive and they were able to track the model flow. However, they did exhibit issues in understanding the difference between non-blocking and blocking human tasks, and they acknowledged the need for a guiding tool that could help them differentiate between the two individual tasks. The internal mechanics of the iStar diagram were not so easy to comprehend. There was significant difficulty in understanding the nature of the dependencies (e.g., hard-goal versus soft-goal) as well as the direction of these dependencies. Therefore, the experts' opinions mark a contextual validation of Propositions 1 and 2 (the validity of Preposition 3 requires modeling experience so its validity was not checked via the focus group). This is in line with the study of Horkoff et al. [65] expressing positive correlations between experience and recognizing dependency trajectories within iStar diagrams. An interesting approach that could help with the aforementioned accessibility issue for the iStar technique would be to map (hard)goals in iStar to milestones in CMMN. This would allow the case handlers to leverage their existing knowledge of goals and milestones to create a more cohesive model of the MBA admissions process. Indeed, milestones are business objectives which must be achieved throughout the execution of a particular case. On the other hand, goals refer to "*a state of affairs that the actor wants to achieve and that has clear-cut criteria of achievement*" [66]. Thusly, there seems to be an inference in terms of a goal-to-milestone association which is also supported by the study of Eshuis & Ghose [18]. This alignment is corroborated in the present case study since each goal within an actor's boundary in the iStar SRD indeed corresponds to a milestone. For instance, the *Application Evaluated* goal within the boundary of the actor *Program advisor* is identical to the *Application evaluated* milestone after the completion of the required task *Decide on application outcome*. It could be argued that one-to-one mapping of iStar goals with CMMN milestones could help maintain a degree of semantic consistency between the models.

Table 1. Evaluating Criteria and Propositions with their Corresponding Sources

Evaluation Criterion	**Description**	**Sources**
Accessibility	*Is domain knowledge a prerequisite for modeling purposes?*	[53].
	Proposition 1: CMMN is a user-friendly case management language, while iStar is considered to be a complex social modeling language requiring modeling experience.	[67]; [68]; [69]; [65]; [66]; [39].
Error-proneness	*Does the modeling technique offer support in preventing errors?*	[54].
	Proposition 2: There are modeling tools (e.g., Case Model Discovery) to help validate CMMN models, but iStar requires deep understanding and experience to avoid errors.	[70]; [71]; [6]; [27]; [72]; [73]; [65]; [66].
Resource availability	*Are there enough resources (i.e., manuals, tools, guidelines, etc.) to study the modeling technique?*	[53].
	Proposition 3: CMMN has a detailed specification and modeling tools, while iStar has many online resources and tools (i.e., iStar wiki, piStar, etc.)	[6]; [74]; [66].
Granularity	*Can the modeling technique represent organizational and/or technological systems in various levels of abstraction?*	[56].
	Proposition 4: For CMMN, the abstractive modeling view gives case workers flexibility, while the analytical modeling view represents the exact sequence of activities. The iStar Strategic Dependency and Rationale models show actors' high-level dependencies and internal configurations, respectively.	[75]; [76]; [39].
Combinability	*Does the modeling technique facilitate combinations with other notations/techniques?*	[54].
	Proposition 5: CMMN combines with other process-focused modeling techniques (i.e., BPMN, DMN, etc.) while iStar combines with systems-oriented modeling methods (i.e., UML) to model agent-oriented systems or business requirements.	[77]; [6]; [78]; [79]; [80]; [81]; [56].
Modularity	*Does the modeling technique support incremental development?*	[53].
	Proposition 6: CMMN supports modularity via its use of stages, while iStar does not independently support modularity.	[82]; [83]; [84]; [39]; [85].
Scalability	*Does the modeling technique accommodate scalability?*	[56].
	Proposition 7: CMMN scales well with the use of modularization, but modeling style choices and complexity can affect scalability. iStar does not scale well for large systems due to overloaded models and cross-cutting links.	[86]; [82]; [87]; [39]; [88]; [89]; [90].
Domain applicability	*Which domains favor the use of the modeling technique?*	[53].
	Proposition 8: As a declarative language, CMMN is suitable for modeling knowledge-intensive processes, while iStar is suitable for modeling organizational ecosystems and/or systems requirements.	[26]; [2]; [67]; [91]; [92]; [39]; [93]; [94]; [31]; [95]; [80]; [96].
Workflow support	*What is the modeling technique's capacity to accommodate the support of workflow elements?*	[55].
	Proposition 9: CMMN inherently supports workflows, while iStar focuses on actor intentions.	[86]; [84]; [75]; [97]; [98].
Social focus	*What is the modeling technique's capacity to accommodate the support of goal-modeling elements?*	[56].
	Proposition 10: CMMN can be adapted to include social features (i.e., users, roles, permissions etc.) while iStar is well-suited for modeling the social statuses in organizations.	[82]; [6]; [2]; [39]; [99].

Granularity, Combinability, Modularity, and Scalability of CMMN and iStar. Overall, the CMMN technique was perceived effective in modeling the MBA admissions process because it offers a range of task objects and decorators which allow for the management of complexity within the process itself and the simulation of extraordinary events (or changes) due to the emergence of additional work process specifications. For instance, the repetition decorator within the *Verify file completeness* task in stage 1 in Figure 1 empowers a case handler to ask for more documents from a potential applicant; this seems to closely approximate the reality of the admission process. On the other hand, the iStar diagrams were perceived to be offering a 'correct' snapshot of the actors and their intentions at a specific moment in time. Their biverse representation of two distinct viewpoints (i.e., a high-level representation of actor relationships provided by the iStar SDD, combined with the intricacies of actor compositions provided by the iStar SRD) offered traces of granularity. Therefore, there are elements in the case study to support the validity of Preposition 4. However, the iStar diagram was deemed too 'rigid' to accommodate the level of flexibility that case handlers require when having to occasionally re-organize the admissions process due to the inflow of an excessive number of applications for the MBA program. The argument was that, in such cases, new iStar diagrams would probably be needed, as Figure 2 would not uphold to the intentions of the actors when priorities change and different work patterns emerge. So, whereas iStar was perceived to be 'disobliging' in terms of supporting incremental development, the CMMN diagram was perceived to score better in modularity with the use of distinct stages, thus Prepositions 6 and 7 seem to stand true. Tasks in the iStar SRD were identified as mere descriptions (i.e., means-to-an-end) of some top-level hard goals. However, decomposing such tasks into smaller chunks of activities seemed to facilitate the recognition responsibilities owned to each actor. This contrasts with CMMN tasks, which were perceived as 'black boxes' that do not provide enough information about internal activities, nor their proprietor. Therefore, it makes sense to investigate whether an "alignment" can be conceptually perceived between tasks in iStar and tasks in CMMN. A task in iStar is defined as an action that an actor wants to be executed, usually with the purpose of achieving some goal [66]. A task in CMMN represents activity (work) that needs to be carried out in the organization, and it can be further refined in many types (i.e., blocking human task, process task, etc.) [6]. So, a task refers to some form of executable work in both languages. Within the case study, in Figure 2, there are 4 parent-level tasks connected with means-to-end links to 4 hard-goals. Those parent-level tasks in iStar SRD can be traced to human tasks bearing a required decorator in CMMN. For instance, the *Verify file completeness* parent task may correspond to *Verify file completeness* human task with the required decorator. Additionally, all required human tasks are connected via sentries to a milestone. Therefore, future work should study whether a formal tasks in iStar can be formally corresponded to tasks-to-milestones relationships in CMMN. This would require a technical evaluation of both techniques and is out of scope for the present study. Additionally, the context of the particular case study could not be used for the validation of Proposition 5.

Domain applicability, Workflow support, and Social focus of CMMN and iStar. There was a general consensus that the MBA admissions case needs to allow for human decision-making at run-time, and CMMN models facilitate this through the use of sentries. For instance, the sentries in stages 1 and 3 of the CMMN diagram in Figure 1 specify the behavioral patterns that guide the flow of execution of the subordinate activities described within those stages. Nevertheless, such behavioral patterns seem to be bereaved of their corresponding roles that need to take charge of their fulfillment. So, the CMMN diagram (Figure 1) does not explicitly define which actors are involved in which part of the process, nor does it specify their roles and responsibilities. Contrarily, the iStar diagram in Figure 2 distinctly captures this through the represented dependencies among the *Program advisor*, the *Applicant*, and the *Credential evaluator* actors. Therefore, the knowledge-intensive nature of the MBA admissions case does not preclude the use of iStar. Hence, while Proposition 9 seems to stand, the validity of Propositions 8 and 10 could not be verified in practice. Interestingly, in the particular case study, all iStar resources seemed to be traced back to the case file items in the CMMN diagram. For instance, Figure 2 shows that the iStar resource *Eligibility report* resource is needed to complete the iStar task *Read eligibility report*. However, the same kind of relationship is exhibited in the CMMN diagram of Figure 1, where the case file item *Eligibility report* is a prerequisite for the execution of the human task *Read eligibility report*. The same is consistent for the relationships describing the CMMN case file items *Application file* and *Authentication database* and their corresponding tasks *Check files submitted* and *Access authentication databases*. This raises the question of a possible complementarity between the two modeling notations for these techniques. In fact, iStar resources are defined as a physical or informational entity that the actor requires in order to perform a task [66], [11]. Case file items, on the other hand, are meant to represent any kind of information, unstructured or structured, simple or complex [67]. Thereby, both elements are cited in the literature as artifacts containing relevant information to the modeling scenario/case. We propose a furtherance of the investigation between iStar resources and CMMN case file items as future work.

Overall, the findings from the case study, as perceived by the domain experts, are encapsulated in Table 2. Summarizing these findings, we highlight some benefits from the combinatory approach that were perceived in the case study, which indicate a plausible complementarity between the two modeling techniques. First, experts perceive specific challenges with each modeling technique when applied individually to the case. However, these challenges appear to be mitigated when the domain problem is approached in conjunction with the use of both modeling techniques. For instance, while CMMN diagrams are considered intuitive for tracking model flows, they may lack clarity in distinguishing between non-blocking and blocking human tasks. In contrast, the iStar diagram, in this case study, provides the necessary elements for a more nuanced analysis of the tasks assigned to actors and the actions required to achieve predetermined case goals. For the case study under discussion, the predetermined alignment of iStar goals with CMMN milestones underscores the importance of assessing semantic consistency between the two techniques, facilitating cohesive modeling and leveraging existing knowledge. However, the steep learning curve associated with iStar, the absence of actor provision and accountability in CMMN, and the differing levels of granularity required by each technique are recurring challenges that must be overcome to make this complementarity feasible.

Table 2. Validation of Propositions: Summary of Expert Opinions

Proposition	Short Description	Validation Outcome
1	User-friendliness of CMMN and iStar	CMMN notations more user-friendly
2	Model validation in CMMN and iStar	CMMN diagrams easier to validate
3	Tool availability in CMMN and iStar	Experts not aware of specific tools
4	Modeling views in CMMN and iStar	Both offer diverse modeling perspectives
5	Integration with other modeling techniques	Experts not aware of integration capacities
6	Modularity support in CMMN and iStar	CMMN appears to be more modular
7	Scalability comparison in CMMN and iStar	CMMN appears to be scalable
8	Use context for CMMN and iStar	Experts could not verify
9	Modeling focus of CMMN and iStar	Experts perceive common ground
10	Modeling Adaptability of CMMN and iStar	Experts could not verify

6 Discussion

Our analysis indicates that the iStar diagram (Figure 2) presents a relatively steeper learning curve and a more intricate structure compared to its CMMN counterpart. This makes the former less effective as a comprehensive blueprint for identifying syntactical errors in the context of the MBA admissions case (validity of Propositions 1 and 2). This seems to be in accordance to the affirmations that can be retrieved in the software modeling literature which seem to mention the requisition of experience very important when pursuing a particular modeling exercise with iStar. Despite the existence of a number of iStar-affiliated resources, these can be perceived merely as tools meaning to augment the overall modeling experience of a relatively experienced modeler rather than acting as the guiding reference to bring an inexperienced modeler up to speed with iStar modeling conventions. On the other hand, simply by explaining the modeling notations of the CMMN technique, the experts seemed to have acquired a thorough grasp of the CMMN diagram and were even able to recognize modeling oversights during the presentation of the draft CMMN diagrams during the first round of interviews. This fact, in combination with its provided support for iterative modeling development (via the use of distinct stages) and the flexibility it provides to case handlers to alter (or completely skip) task sequences (Validity of Propositions 4 and 6), renders the CMMN as an effective tool to provide a 'rough sketch' of a particular domain problem, before inaugurating more formal requirements engineering processes for the development of technology-reliant systems. However, within the case study, there are no evident causes for the dismissal of the use of the iStar diagram. In fact, during the first round of interviews, the experts utilized the draft version of the iStar diagram as a perspective enhancer to visualize the mosaic of all the actors that are involved in the MBA process, before starting to comprehend the sequences of the tasks within the process itself. So, the iStar diagrams offered an abstractive way to view the players in the particular case while the CMMN diagrams assisted in the operationalization of the tasks for these players. In this way, there were elements in the particular case justifying the in-parallel use of both modeling techniques. Such elements referred mostly to the goal-to-milestone, task-to-milestone, and task-to-sentry convergences between the two techniques. We point towards the formal association of the aforementioned elements as a future trajectory of the present work.

7 Threats to Validity

Some threats to validity are considered according to the prescriptions of Wohlin et al. [100]. In particular, *threats to the construct validity* take the form of commentary misappropriations when explaining the notations of the suggested modeling languages to domain experts, which may lead to communication lapses between the last ones and the research team when preparing the visual diagrams. To counter that effect, the interviewer has allotted enough time before the start of the first focus group to explain the notations of each framework as well as provide information for its corresponding parts and significations. The same procedure was repeated before the start of the second round of interviews, using Figures 1 and 2 as visual guiding aids. The choice to utilize these diagrams as single visual indicators to compare the two modeling techniques seems to be justified in the studies of Tsilionis et al. [101], [102] and Vemuri et al. [103]. These studies mention that even inexperienced software modelers – such as our domain experts – seem to be able to offer valuable insights and to be able to comprehend the representations (visualizations) of a software-related problem if they are offered step-by-step instructions and contextual information regarding the problem at hand.

Contrastingly, *threats to the internal validity* are explicated as errors that occur during the knowledge acquisition process and affect the present study to produce objective inferences. In our case, one concern was that the experts' responses might be biased by their growing understanding of the techniques and notations as the interview progressed. This is because the propositions they were asked to evaluate already implied (or expressed directly) certain opinions about the ease of use and perceived complexity of each technique. To reduce this risk, we used the visual diagrams as the primary source of debate when evaluating the propositions. We also paid special attention to the use of objective and 'uncolored' words/terms in our description of the two techniques (and their corresponding notations) and subsequent questions during the interviews. However, the use of domain experts, non-experienced in software modeling, might also be raising some *threats to the external validity*, deterring the generalization of the findings of the present study to other contents. Notwithstanding, we consider the recruitment of domain experts not to be threatening the ecological validity [104], [105] of the outcomes of the study. This is because any business or organization in the phase of (re)designing a process or a software-driven solution necessitates the need of communication between non-technical stakeholders (experts expressing domain requirements) and software modelers. Therefore, the diagrams produced by such modeling languages, as well as their accompanied notations, should not be considered encrypted shibboleth by non-technical experts.

At this point, it is important to mention that we do recognize a potential limitation in our study due to our reliance on experts from a specific domain, namely education, which raises concerns about the broader applicability of our findings. Indeed, the use of a single case study and a limited number of experts may not fully capture the complementarity between CMMN and iStar in domains beyond education. However, our study's scope extends beyond the question of merely accepting complementarity between CMMN and iStar across various domains. In that scenario, the implementation of grounded theory, with its iterative cycles of data observation, analysis, and theorizing [106]) would be better suited for validating or refuting definitive areas of convergence between the two techniques. Our study on the other hand, aims to communicate a methodological approach that should guide the commencement of investigation of areas of reciprocity between different modeling techniques. Our study communicates that such an approach should involve pluralism in terms of data collection methods, including literature reviews, document analysis, expert opinions, whereas the implementation of a case study should only be used as the focal point for analysis in the process of derivation of meaningful insights. In alignment with Seddon's findings regarding the cautionary generalization of results from single case studies [107], we refrain from claiming a universal truth on the osculating points of CMMN and iStar based on our findings. Instead, we view our results as a starting point for further exploration and understanding, highlighting a methodological approach in the search to uncover truth rather than asserting its universality.

8 Conclusion

One of the objectives of this article is to address the limited amount of established objective criteria in the academic corpus of literature that could aid in studying the representational capabilities of diverse modeling techniques, in the effort to identify potential synergies and interdependencies. At this stage, we can get back to the research question stated in the introduction as *'how can the complementarity of Adaptive Process-Centric (CMMN) and Social-Oriented (iStar framework) Modeling Techniques enhance the semantic representation and analysis of complex domain problems?'*. To answer this question, we have discussed the development of a particular methodological approach. This approach outlines a thorough examination of existing literature to identify and refine specific criteria for a comprehensive evaluation of CMMN and iStar. Subsequently, the methodology validates the literature review findings with the conduct of a second-stage literature review to identify a set of pertinent propositions, aiming to scrutinize various performance aspects of the aforementioned techniques. The literature suggests no obvious signs of complementarity in terms of the modeling techniques' generic quality characteristics. For instance, CMMN is deemed versatile in terms of its accessibility, while iStar is considered more complex and requires significant experience to accommodate its use. However, the production of diagrams for a specific case study reveals elements of congruence between the two, as there were traces of alignment between the way iStar goals and CMMN milestones were represented within the case. Second, the literature suggests some partial overlap in terms of how some design elements are perceived for both techniques. For instance, studies reveal that both techniques offer elements of granularity (i.e., abstractive/analytic views for CMMN and SDD/SRD for iStar), with CMMN demonstrating an edge in terms of modularity. Indeed, the case study highlighted the comparable manner in which tasks were represented in both techniques. In fact, certain issues associated with the way tasks are represented in CMMN (they were perceived as black boxes by the experts) could be addressed by employing the iStar diagram in parallel (i.e., the decomposition of tasks in iStar enhances task legibility). Last, the literature seems dismissive of the consistent symbiosis between the two techniques, as CMMN is confined into a workflow-supporting role for a particular case while iStar is demonstrative of the intentionality among actors in business (and technological systems) ecosystems. Nonetheless, the present case study calls for a sequential adoption of the two techniques, where iStar is used first to map the actors that participate in the process and then CMMN is used in a more granular manner to sketch the activities for these actors. For future work, we would point out the investigation of the achievement of a formal alignment between the notations of the CMMN and iStar techniques. This would require a larger case study, in terms of function points and work-breakdown structure, with the engagement of software designers, modelers, and domain experts.

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