

ISIEM: A methodology to deploy a knowledge-based system to support bidding process

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When responding to calls for tenders, companies must elaborate on relevant bids relative to the needs and expectations of customers (for example, in terms of price and delay). We built and deployed a knowledge-based system (KBS) to aid companies when developing bids. Based on a pre-defined generic bid model, a methodology to support companies when deploying the KBS is proposed in this paper. To capture, formalize, and reuse knowledge relevant to bids, a combination of several approaches, such as taxonomy, constraint satisfaction problem, and case-based reasoning, is proposed. The methodology is composed of five steps: *Initialization, Specialization, Implementation, Exploitation, and Maintenance*. A case study from a company building electrical parts of harbor lifting devices illustrates our proposal and allows validating the proposed methodology.

1. Introduction

1.1. Bid development in response to call for tender

Bidding process is critical for many industrial companies. Convincing the potential customer that the company's bid is better than those of competitors in terms of accordance with customer requirements (Van-welkenhuysen, 1998), attractive price, and quick and achievable delivery time is key to winning a call for a tender. To do so, company-specific knowledge is mobilized. Moreover, the response time of the potential customer is often less than the time needed to fully develop a bid (Krömker, Thoben, & Wickner, 1997). Our goal, within the OPERA project¹, is to assist the companies that respond to a call for tenders by providing them with a knowledge-based system (KBS) that supports the development of the bid.

Thus, a generic bid model has already been proposed (Guillon, et al., 2021) (Fig. 1) and is divided into four parts characterizing (1) the context in which the bid is developed, (2) the technical solution (TS) proposed to meet customer requirements, (3) the delivery process (DP) associated with the TS, and (4) the key performance indicators (KPI) used to evaluate the TS and the associated DP, for example, cost, price, margin, or confidence (Sylla, et al., 2017).

The operational use of this model by a company requires the use of a knowledge-based system to assist the company in its response to the call for tenders by structuring, formalizing, and exploiting its knowledge. And this operational use of a KBS must inevitably be accompanied by a method of deployment, capitalization, and exploitation of the necessary knowledge. Thus, the following section describes the chosen formalisms and their articulation to represent the knowledge in the KBS that we have designed, and the remainder of the article focuses on detailing our research question around the methodology of deployment of this KBS in a company.

1.2. The OPERA knowledge-based system

Montani (2011) distinguishes general knowledge (applicable in any context) from contextual knowledge (applicable in a defined context). This knowledge can be more or less precise or imprecise, more or less theoretical or linked to real experiences. In the OPERA KBS, we consider all these types of knowledge to support bid development.

On the one hand, the OPERA KBS considers business rules of the company. These business rules are generic and general knowledge, usually defined precisely and theoretical (as for instance mathematical, physical, or commercial rules). In the OPERA KBS, they are formalized

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¹ OPERA is a French acronym of "Software and tools to support bidding process."

and exploited with a constraint satisfaction problem (CSP) approach (Montanari, 1974). A CSP can be defined as a triplet $(\mathbb{V}, \mathbb{D}, \mathbb{C})$, where $\mathbb{V} = \{v_1, v_2, \dots, v_k\}$ is a finite set of the k variables used to model the problem, $\mathbb{D} = \{d_1, d_2, \dots, d_k\}$ is a set of definition domains of variables, and $\mathbb{C} = \{c_1, c_2, \dots, c_m\}$ is a finite set of the m constraints on problem variables, where a constraint describes combinations allowed or excluded for variable values (Brailsford, Potts, & Smith, 1999). In the proposed model, variables \mathbb{V} describe each part of the bid (context, TS, and DP, cf. Fig. 1). Constraints \mathbb{C} between these variables allow to formalize the business rules. It can be (i) constraints internal to a part of the bid (e.g., between elements of the TS), or (ii) constraints between different parts of the bid (e.g., between context variables, TS variables, or DP variables). Examples are provided in Section 4. Besides, a filtering tool (Debruyne & Bessi re, 2001) is used to propagate the constraints.

On the other hand, knowledge of past bids, i.e. contextual knowledge resulting from the work conducted in the past by the company, is reused through case-based reasoning (CBR) approach (Aamodt & Plaza, 1994; Behbahani, Saghaee, & Noorossana, 2012; Hu, Xia, Skitmore, & Chen, 2016). The CBR is composed of four phases (Aamodt & Plaza, 1994): retrieval, adaptation for reuse (Fuchs, Lieber, Mille, & Napoli, 2014), revision, and retention. It allows the use of a case base containing past scenarios to implement a reasoning by analogy. This notion of analogy is implemented through similarity mechanisms (Bergmann, 2002; Zhou, Chen, He, & Chen, 2010) to identify past cases that are like the case being studied.

The CBR approach is particularly relevant to assist the bidding response because this is a routine situation (i.e., similar tenders regularly dealt by the company). Moreover, previous work has shown the possibility and usefulness of combining the CSP and CBR approaches to help in decision making (Vareilles, et al., 2012).

Each case is described by a set of variables \mathbb{V} , with predefined definition domains \mathbb{D} (Kolodner, 1993). The complete set of variables allows to describe a situation and the proposed solution. For characterising a case, each variable of the case must be valued with a unique value. A distance measure allows to compare the similarity of the different cases stored in the case base with the studied situation (target case). The inference is used during the development of a new bid, after having made some key choices on context and eventually the TS or DP; the user can search for similar cases in the case base and use or adapt the relevant past cases to develop the current bid.

Besides, a common ontology-based vocabulary is defined to better describe business rules and past bids, but also to facilitate the coupling of the two previous approaches. The ontology groups together all objects and concepts that allow describing the knowledge of a given field

(Gruber, 1995; Van Heijst, Schreiber, & Wielinga, 1997). In general, ontologies are organized into element classifications, represented as a tree or graph, which have generalization/specialization as the most common principle. The closer an element is to the root, the more general it is, the further it is away from the root, the more specialized it is (Foguem, Coudert, B ler, & Geneste, 2008). Thus, low-level concepts have the same properties as those of high-level concepts they inherit (Staab & Studer, 2010). To be more specific, the OPERA KBS include a taxonomy, which is a specific type of ontology, without rules.

Each model entity presented previously (Fig. 1) is associated with a concept to enable the reuse of the knowledge. An example is presented in the case study in Section 4. Each concept is described by a set of variables, which are either part of the CSP, of the CBR approach, or both.

1.3. Research question and article organization

The generic bid model proposed in (Guillon, et al., 2021) and the OPERA KBS must go with a methodology for deployment. Indeed, according to Buck (1999) “the implementation of a system of capitalization and sharing of knowledge is subordinated to the use of a suitable methodology. Like any project management, it must follow an iterative and gradual logic”. In addition, each company produces different bids and works differently; thus, it is necessary to define a methodology which can be adapted to the needs of different companies and allows to customize the generic knowledge bases to the specific features of a given company. Up to our knowledge, and we will demonstrate this through the literature review, there is no methodology for the deployment and exploitation of a Knowledge-Based System for offer development, which would allow risk engineering.

Avoiding KBS or information system (IS) deployment failures is also a very strong support to this methodology need. Authors like (Whitney & Daniels, 2013; Dwivedi, et al., 2015) and more recently (Haug, Shafiee, & Hvam, 2019) have analyzed various KBS and IS deployment failures. They clearly suggest (i) that failures can be more attributed to organizational and communication related issues than to technological issues, (b) to better integrate all stakeholders, (c) that team working, project management skills and strong decision making allow to avoid failures. These statements clearly highlight the deployment methodological need, our methodology-based propositions are perfectly in line with them.

Consequently, the aim of this paper is to propose such a methodology, and to answer the following research question: “How to deploy a KBS to support bid development in companies responding to call for tenders?” In addition, this paper is designed as a guide to enable users to

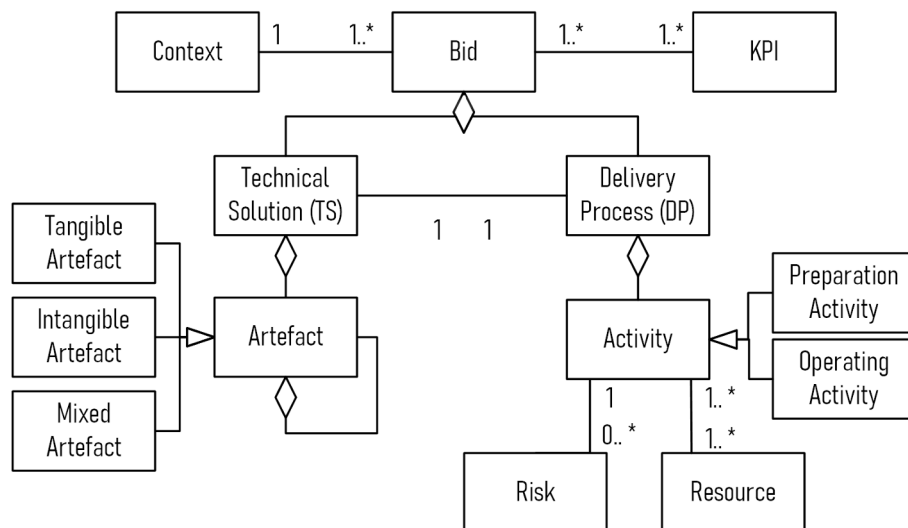


Fig. 1. Generic bid model (Guillon, et al., 2021).

adapt and deploy the proposed methodology for future industrial applications.

The remainder of this article is organized as follows. [Section 2](#) presents a state-of-the-art about methodologies relative to KBS deployment. [Section 3](#) begins with a scientific positioning and then details the proposed methodology. [Section 4](#) illustrates our proposal through a case study from a company that designs harbor lifting devices. Then, [Section 5](#) presents results from the deployment of the proposed methodology in different companies and deduces managerial and methodological implications from these results. Finally, [Section 6](#) concludes this article and introduces some prospects.

2. Related work

This section is dedicated to a state-of-the-art of methodologies and approaches related to KBS deployment. The [Section 2.1](#) is dedicated to methodologies relative to knowledge management. Methodologies for the deployment of information systems (IS) are introduced in [Section 2.2](#). Finally, a synthesis concludes this section ([Section 2.3](#)). We will underline for each methodology, the aspects that will be considered in our propositions. A particular care will be taken to situate each of these methods in relation to the key phases of the KBS life cycle. In the synthesis at the end of this section, the [Table 1](#) will show the positioning of all these methods with respect to the KBS life cycle.

2.1. Methodologies relative to knowledge management

2.1.1. Knowledge management approaches

According to ([Grundstein, 2000](#)), the question of capitalization on companies' knowledge is characterized by four facets:

- **Locate.** Identifying and characterizing the knowledge.
- **Preserve.** Formalizing and conserving the knowledge.
- **Enhance value.** Disseminating and using more effectively the knowledge.
- **Maintain.** Updating the knowledge.

[Hu, Hou & Chen \(2019\)](#) have identified four main stages (*Knowledge gathering, Knowledge enhancement, Knowledge reuse and Knowledge sharing & transfer*) that allow them to group together the mechanisms they use in their knowledge management framework (UNISON).

Finally, [Kimiz \(2005\)](#), after a literature review on knowledge management, proposed an integrated knowledge management cycle composed of three main stages, shared by all the studied references:

- Knowledge capture and/or creation, which corresponds to *Locate* facet of Grundstein approach or to *Knowledge gathering* stage of UNISON framework.
- Knowledge sharing and dissemination, which corresponds to *Enhance value* and *Maintain* facets of Grundstein approach or to *Knowledge enhancement* and *Knowledge sharing & transfer* stages of UNISON framework.
- Knowledge acquisition and application, which corresponds to *Preserve* facet of Grundstein approach or to *Knowledge reuse* and *Knowledge sharing & transfer* stages of UNISON framework.

Thus, Grundstein approach seems more complete and the proposed methodology, which is relative to knowledge capitalization, should deal with these facets.

2.1.2. CommonKADS methodology

The CommonKADS methodology (Common Knowledge Acquisition and Design System) is the result of two European projects KADS-I ([Wielinga, Schreiber, & Breuker, 1992](#)) and KADS-II ([Schreiber, et al., 2000](#)). It aims at giving a structured approach to KBS deployment. This methodology is model-driven: six models are proposed to deal with

complexity of knowledge management process ([Schreiber, et al., 2000](#)). The methodology is composed of three phases, during which the models are instantiated:

Context. The first phase is about understanding the organizational context and environment. "Why is a knowledge system a potential help or solution? For which problems? Which benefits, costs, and organizational impacts does it have?"

Concept. The second phase is about the conceptual description of the knowledge. "What is the nature and structure of the knowledge involved? What is the nature and structure of the corresponding communication?"

Artefact. The third phase is about the technical aspects of the computer realization. "How must the knowledge be implemented in a computer system? How do the software architecture and the computational mechanisms look?"

Although the CommonKADS methodology has today more than 20 years, it is still up to date for KBS creation. More recent works concern its application: [Sutton and Patkar \(2009\)](#) and [Xavier et al. \(2013\)](#) in medical domain, or [Saleh et al. \(2018\)](#) who propose an enhancement of the methodology in order to improve its operational reusability. Concerning its link with our work, the separation in three phases ([1] Current situation analysis, [2] Knowledge modelling, [3] Implementation) is particularly relevant and will be transposed to the proposed methodology.

2.1.3. MASK method

The MASK (Method of Analysis and Structuring Knowledge) method offers a flexible environment that allows to success knowledge capitalization projects ([Matta, Ermine, Aubertin, & Trivin, 2002](#)). The MASK method adopts three points of view to describe knowledge: information, meaning and context, with models associated to each view ([Saulais & Ermine, 2019](#); [Saulais & Ermine, 2020](#)). A MASK project includes two phases:

Scoping phase. The workload associated with modelling is substantial if all models are instantiated. However, the complete modelling cycle is not always necessary depending on the project. Therefore, this phase aims to identify the relevant models according to the objective and specificities of the project.

Modelling phases. These modelling phases integrate the MASK models:

- First, the information-related elements are modelled.
- Then, the expert gives meaning to the information previously identified thanks to the model of concepts (like a taxonomy) and the model of tasks (flowchart of tasks).
- Finally, the context models are instantiated: the business rules are formalized in a structural (domain model) and functional (activity model) ways.

These elements must be considered to build our own knowledge-related methodology.

2.2. Methodologies for information systems deployment

2.2.1. GRAI engineering method

GRAI² integrated methodology (GIM) is a methodology developed to address production management decisions in manufacturing systems ([Aguilar-Savén, 2004](#)).

GIM has been extended by [Merlo and Girard \(2004\)](#) to introduce knowledge management for the domain of product development companies. The resulting GRAI Engineering method is composed of four main phases:

² *Graph à Résultats et Activités Interreliés* - Graph with Interrelated Results and Activities

Table 1
Synthesis of phases in knowledge methodologies.

Phase	Initialization	Modelling	Implementation	Exploitation	Maintenance
Grundstein	Locate	Preserve	/	Enhance value	Maintain
CommonKADS	Context	Concept	Artifact	/	
MASK	Scoping phase	Modelling phase	/	/	/
GIM	Initialization	Modelling & Design	Implementation	/	/
ARIS	/	4th phase	5th phase	5th phase	/

Initialization phase. Information and training on methodology, definition of goals and field of study, planning of study, definition of different groups of actors involved.

Modelling phase. Based on the existing engineering design system which leads to the establishment of a diagnostic of necessary improvements. Several views are established to understand organization structure and functions, business processes and existing information system.

Design phase. For the modelling of a new engineering design system and for the specifications of the information system that will provide the required assistance to design people for design coordination. Knowledge modelling is integrated as a view according to initial objectives.

Implementation phase. The new information system is deployed after selection and/or development steps.

Like KBS approaches, GRAI engineering method also offers a set of models for building the future information system considered as a knowledge-based system. It focuses on the analysis phase of the existing system to better assess the impact of the planned specifications on the organization of the company as well as business users. These considerations are essential to the methodology that we propose.

2.2.2. ARIS

ARIS (Architecture for Integrated Information Systems) creates a guideline for developing, optimizing, and implementing integrated application systems from a process point of view (Scheer & Schneider, 2006). The deployment of ARIS architecture is composed of five phases:

- **Phase 1.** Definition of the IS-oriented initial strategic situation,
- **Phase 2.** Requirements definition,
- **Phase 3.** Design specification,
- **Phase 4.** Implementation description,
- **Phase 5.** Runtime: exploitation and maintenance.

The first four phases are about “build time”. As in GIM, a modelling phase of “As Is” is followed by a definition of the system “To Be”. This deployment phases encompass all stages of the IS life cycle, from specifications to maintenance, passing by implementation. The OPERA KBS will be already developed. Thus, specification and development phases do not fall within the scope of our methodology. However, the steps of implementation, exploitation and maintenance will have to be considered. More recently, Santos, Almeida and Pianissolla (2011) have proposed an approach to excavate and define the metamodels of the organizational modelling and business process modelling languages of ARIS method.

2.3. State-of-the-art synthesis

The Table 1 summarizes the findings of the previous state-of-the-art:

- The *Initialization* phase can be found in all studied methodologies except ARIS.
- The *Modelling* phase can be found in all methodologies without exception.
- The *Implementation* phase can be found in the CommonKADS methodology proposed by Schreiber, Akkermans et al. (2000) and in ARIS methodology.

- The *Exploitation* phase can be found in the knowledge cycle proposed by Grundstein (2000) and in ARIS methodology.
- The *Maintenance* phase can be found in the facets of the knowledge cycle proposed by Grundstein (2000).

3. Proposed ISIEM methodology

This section is dedicated to the proposal of a methodology to implement the OPERA KBS. This methodology will be illustrated by a case study in Section 4.

3.1. Preamble to the proposed methodology

ISIEM methodology has been developed in the framework of the OPERA project. It means it is designed for companies with the following characteristics:

- The company responds to call for tenders, i.e., identified, and documented customer’s needs. It also means B2B (business to business) situations.
- The development process is mainly in CTO (ATO or MTO)³. Only a small part of the designed solution is ETO. It means the bid development is a routine situation and the company has knowledge to be formalized (Chandrasekaran, 1986).
- The company sells products, services, or product-service-systems (PSS) (Mont, 2002). The bid model proposed in (Guillon, et al., 2021) is suitable for all these cases.
- The company respond to call for tenders for public or private markets. In both cases, the bidding process stay roughly the same and the bid elaboration is not impacted by this factor.
- The company works in industry. We have not studied the bid development in other fields, as bank for instance.

The proposed methodology is composed of five phases, corresponding to the ones previously identified thanks to the state-of-the-art (Fig. 2):

- **Phase 1.** Initialization,
- **Phase 2.** Specialization,
- **Phase 3.** Implementation,
- **Phase 4.** Exploitation,
- **Phase 5.** Maintenance.

Phases 1 to 3 concern the deployment of the OPERA software, and phases 4 and 5 its use. Each phase is composed of steps, composed of activities. As the methodology progresses, the bid model becomes more and more specific to the company concerned. We have called the methodology ISIEM, which is an acronym of the phases (Initialization, Specialization, Implementation, Exploitation, Maintenance), and because it sounds “easy M”, as “easy methodology”.

The scientific interest being on how to move from the generic model (presented in the introduction) to the model specific to a company, the

³ CTO: Configure-to-order, ATO: Assemble-to-order, MTO: Make-to-order, ETO: Engineer-to-order.

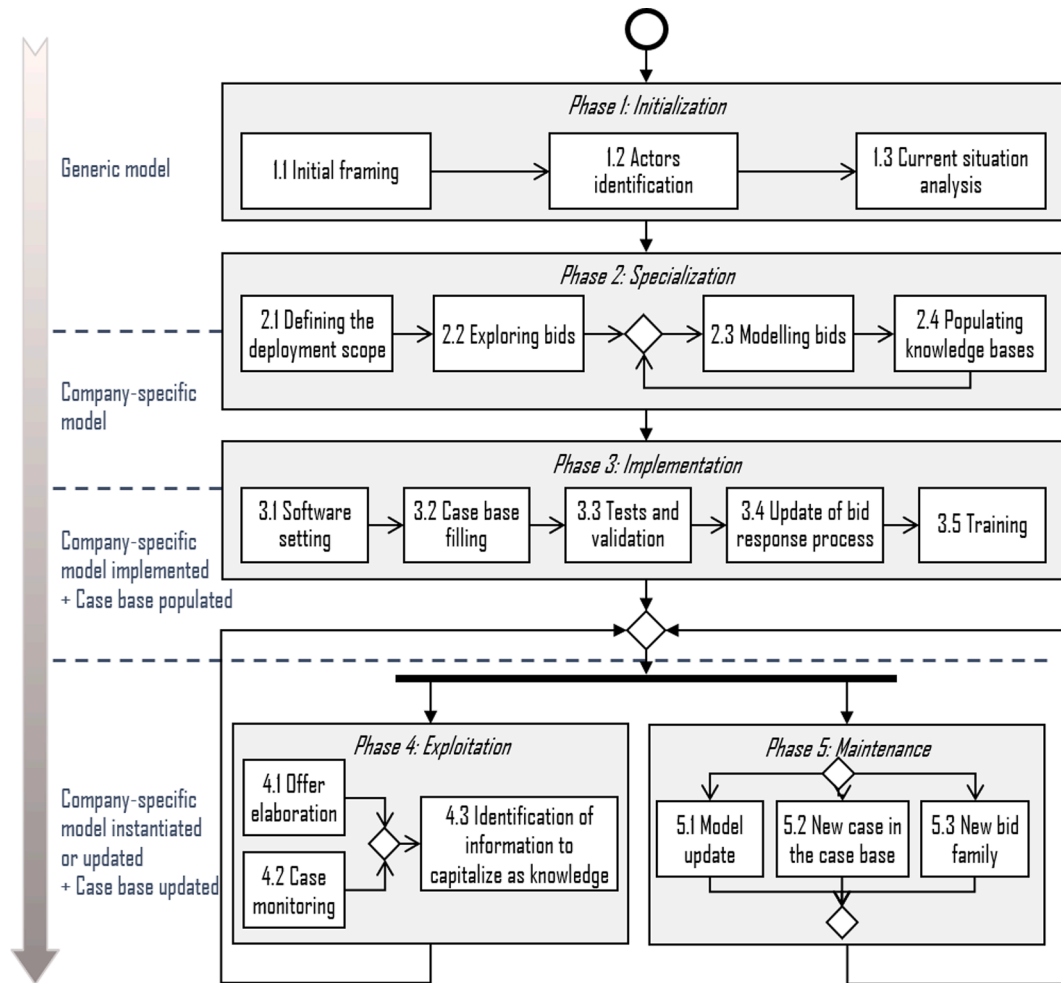


Fig. 2. ISIEM methodology.

accent is put in this article on Phase 2 – *Specialization*. Phase 1 – *Initialization* and Phase 3 – *Implementation* are oriented towards the operational deployment of the model and the associated software tool. In Phase 4 – *Exploitation*, the software is used for bid elaboration. Finally, Phase 5 – *Maintenance* concerns the continuous monitoring of the tool. The following sections are dedicated to each phase of the ISIEM methodology.

3.2. [Phase 1] Initialization

The objective of the first phase *Initialization* is to define the scope of the KBS deployment project. It allows identification of the stakeholders within the company, to understand the expectations and the functioning of the company, and finally to define the scope and the planning of the study. Meetings with the people in charge of the KBS deployment in the company allow to identify the previous information. This *Initialization* phase is broken down into three successive steps.

The first step, (1.1) *Initial framing*, is a strategic milestone with the executive management of the company, at the start of the project. It allows validation of the expectations and objectives of the company relative to the KBS deployment, and to identify if they cope with the improvement linked to the deployment of the KBS. The scope of the study is determined. In addition, it allows defining the means allocated to the project and a provisional timetable.

During the second step, (1.2) *Actors identification*, people involved in the KBS deployment are identified: the project manager, and experts owning the required knowledge that need to be interviewed.

The final step of this first phase, (1.3) *Current situation analysis*, aims at understanding how the company responds to a call for tenders and the maturity of the company about KBS.

At the end of this phase, the scope of the project of knowledge formalization is defined.

3.3. [Phase 2] Specialization

The objective of the *Specialization* phase is to formalize the company knowledge necessary to elaborate bids. This phase details how to move from the generic model described in the introduction to a model specific to the studied company. This phase is composed of four successive steps.

3.3.1. Step 2.1: Defining the deployment scope

Regarding the scope previously defined, the objective of the first step is to identify the operational scope of the study and some model restrictions specific to the company. The person in charge of the KBS deployment, named OPERA expert, will interview the project manager and a knowledge expert. This step is composed of two successive activities.

The first activity is (2.1.1) *Representative bids identification*. At first, the KBS may not be deployed on all the bids of the company. The OPERA expert must identify a bid family on which the KBS relevancy and usability will be tested first. We call these bids “*representative*”. This bid family is chosen from the recurrent bids, for which the company has a strong expertise. Besides, some past bids (relative to this representative bid family) are identified to be used in the case base.

The second activity is (2.1.2) *Specific restrictions identification*. The conceptual model presented in Section 1 is very generic: the technical solution can be decomposed into an infinite number of artefacts, the delivery process can be decomposed in sub-processes composed of an infinite number of activities, etc. To facilitate the comprehension and the use by companies, we proposed to put some restrictions on the model: for example, a maximal number of decomposition levels for the TS and the DP can be determined, and a constraint on the form of the process (i.e., in parallel or in a series) can be defined.

At the end of this step, a representative bid family to deploy the KBS would have been selected and some modelling restrictions would have been identified.

3.3.2. Step 2.2: Exploring bids

The objective of this step is to identify the knowledge, to understand what should be modelled (the bid). Work groups and work sessions with a knowledge expert are alternated to identify the knowledge, to give it back to other experts, and to reformulate it. A vocabulary adapted to the company is used. This is an iterative step, where three different activities may be carried out several times to approach the completeness of the collected knowledge.

The activity (2.2.1) *Bid elements identification* aims at identifying the different elements of a bid for the defined scope. These different elements can be studied in parallel.

What is the structure of the company-specific TS? What are the descriptive attributes of the elements composing this TS? What are the activities to carry on delivering the TS to the customer? What are the context elements that have an impact on the proposed TS or on this DP?

The second activity, (2.2.2) *Business rules identification*, is dedicated to the identification of business rules necessary for bid elaboration. These rules may concern any part of the bid, and as seen previously, can be internal to a part or between different parts of the bid.

The result of the two previous activities must be validated by all experts involved in the KBS deployment during the third activity, (2.2.3) *Validation of the exploration phase*.

At the end of this step, knowledge necessary to develop bids have been identified and partially modelled, thanks to the generic bid structure.

3.3.3. Step 2.3: Modelling bids

This step aims at modelling the bid with knowledge gathered during the previous step. The OPERA expert meets the knowledge experts to validate the model. This step is composed of four successive activities.

The first activity is (2.3.1) *Concepts identification*. Based on the elements gathered during the activity (2.2.1), concepts describing the bid are identified and associated with each part of the model (Context, TS, DP, or KPI). We proposed four upper-level generic concepts to describe the Context part: *Customer characteristics*, *Characteristics of the call for tenders*, *Internal environment*, and *External environment* (Guillon, et al., 2021). For the TS, a concept is associated to each component family; for the DP, a concept is associated to each activity; and concepts are associated to each KPI.

The second activity is (2.3.2) *Variables identification*. Still owing to the elements gathered during the activity (2.2.1), variables describing each concept are identified and the definition domains of these variables are set, so they can be used in the CSP model and cases base structure.

During the third activity, (2.3.3) *Knowledge bases structuring*, concepts identified are structured in a taxonomy. Business rules identified previously are translated as constraints structure using variables. The architecture of the case base is identified; in addition, local and global similarities are defined.

All elements of the model defined during this step are validated with the experts of the company in activity (2.3.4) *Validation of the modelling phase*.

At the end of this step, knowledge vocabulary is defined and is consistent.

3.3.4. Step 2.4: Populating knowledge bases

This step aims to populate the knowledge bases, i.e., to formalize the constraints and to fill the case base with past bids. The OPERA expert oversees the formalization of knowledge, thanks to the interviews with the experts in step (2.2). However, as in step (2.3), further exchanges may clarify some points. To achieve this knowledge formalization step, the three following activities can be conducted in parallel.

First activity is (2.4.1) *Constraints formalization*. All business rules between variables, identified during activity (2.2.2), are formalized as constraints. Thus, the constraint tables and formulas that link the variables between them are defined. An example is presented in the case study in Section 4.

Second activity is (2.4.2) *Past cases formalization*. To populate the case base, pertinent past cases (i.e., complete case about the representative bid) are identified. All relevant data about these cases are retrieved from digital or paper files and are used to valueate descriptors of the case base structure. At a minimum, past cases identified for the representative bids in activity (2.1.1) are reused.

Third activity is (2.4.3) *Model consolidation*. In parallel to the formalization activities, models are updated (1) by adding new identified concepts to the taxonomy, (2) by modifying CSP variables or their definition domains, or (3) by adapting the knowledge base structure, in accordance with the reality of the usable data discovered in the company.

At the end of this phase, all relevant knowledge has been identified, extracted, validated, and formalized.

3.4. [Phase 3] Implementation

The objective of Phase 3 – *Implementation* is to implement the company-specific model into the OPERA KBS. The first step is (3.1) *Software setting*. The concepts, variables, constraints, and structure of the past cases base are implemented in the OPERA KBS. Then, using past cases previously formalized at step (2.4), the past cases are implemented during step (3.2) *Case base filling*. Third step is about (3.3) *Tests and validation*: using pre-established cases, the software is tested to compare software's output and expected ones. Fourth step is (3.4) *Update of bid response process*. Following the first uses of the OPERA KBS, the company former bid response process is updated with new practices and the new bid process is formalized. Then, fifth step is (3.5) *Training*. It is adapted to each role of user profile: e.g., technical expert or sales agent.

Once the three first phases are achieved (*Initialization, Specialization, and Implementation*), the company is ready to exploit the model to elaborate new bids using the OPERA KBS.

3.5. [Phase 4] Exploitation

The objective of the fourth phase *Exploitation* is the operational use of the KBS to elaborate new bids and update knowledge. The phase is composed of three steps (Fig. 2). The first step (4.1) *Bid elaboration* is about valuating variables of the bid model, by using the CSP, adapting past cases, or both. This step is the main objective of the methodology. All the other steps aim at supporting the proper conduct of this step. The second step is (4.2) *Case monitoring*. When a bid is accepted by the customer, it becomes an affair. The user can update the case with new information. It allows to compare what were planned with what have been happened. If a component or a resource have been unavailable or modified, this information is noted in the software. The third step is (4.3) *Identification of information to capitalize as knowledge*. The user of the OPERA KBS can identify relevant elements to capitalize as knowledge: it can be new concepts for the taxonomy, an update of the CSP, or a new case to include in the case base.

3.6. [Phase 5] Maintenance

The fifth phase *Maintenance* is about updating the knowledge

contained in the OPERA KBS. Three types of updates can be necessary and are detailed in three concurrent steps of the methodology (Fig. 2):

- the update of the CSP model: step (5.1),
- the addition of a new case in the case base: step (5.2),
- the addition of a new bid family: step (5.3).

The objective of the first step (5.1) *Model update* is to maintain the specific model with the new knowledge as the company responds to new calls for tender. These modifications in the knowledge model can only be done by an expert. Indeed, some of these modifications, as adding a new concept or a new parameter describing a concept, can impact the structure of the knowledge model.

The objective of the second step (5.2) *New case in the case base* is to add new cases in the case base, as new bids are developed and submitted to customers. The knowledge expert studies the cases submitted by the user during step (4.3). If it contains relevant new knowledge, it is added to the case base.

Once the OPERA KBS is effectively operational on the bid perimeter initially defined during step (2.1), the company will probably wish to extend it to new bid family. It is the aim of the third step (5.3) *New bid family*. To do so, Phase 2 – *Specialization* and Phase 3 – *Implementation* are entirely redone with this new bid perimeter.

3.7. Methodology synthesis

The methodology proposed in this section allows populating the generic knowledge bases proposed in introduction with the company-specific knowledge. This methodology consists of five steps:

- Phase 1 allows understanding the company context and defining the scope of work.
- Phase 2 aims to understand the bids to be modelled and concerns the modelling itself.
- Phase 3 is about software implementation.
- Phase 4 is about the KBS daily use.
- Phase 5 allows the maintenance of knowledge contains in the KBS.

The next section is dedicated to a case study to illustrate this methodology.

4. Application of ISIEM methodology: Case study in an industrial company

This section is about applying the ISIEM methodology in companies. The applicability of the methodology proposed in the previous section is shown through a case study from the OPERA project. As part of this project, we worked with a design office in which six people respond to calls for tenders for harbor lifting devices in public or private markets. This company works solely on the electrical part and collaborates with a partner for the mechanical part of these devices.

4.1. Deployment of phase 1 – Initialization

(1.1) *Initial framing*. Our main interlocutors were the expert and international coordinator. It appears that the objective of the company is to increase the success rate by (1) reducing the response time and increasing the response number and (2) elaborating relevant bids using expert knowledge.

(1.2) *Actors identification*. We identified two types of roles who will use the software: one expert and several technical users. The expert (sales manager) and one of the technical users (international relationships coordinator) have been involved all along the deployment of the methodology.

(1.3) *Current situation analysis*. The company submits around 200 bids per year, among 10% concerning new harbor lifting devices in

public or private markets.

4.2. Deployment of phase 2 – Specialization

(2.1) *Defining the deployment scope*. Concerning the *Representative bids identification*, the company chooses the bids about *new harbor lifting device*. These bids represent an important workload and turnover. In addition, the company is an expert on the subject.

To reduce the complexity of the model for future users, and because we limit ourselves to a “Proof of Concept”, some *Specific restrictions* on the generic model have been identified. Thus, the DP will be sequential and the decomposition of the TS in subsystems will be limited to three levels.

(2.2) *Exploring bids*. The first activity is *Bid elements identification*. Meetings with the expert have enabled identification of the different parts of a bid. These elements are relative to (1) the context in which the bid is developed, (2) proposed TS, (3) DP associated to this TS, and (4) KPI to evaluate bids.

- (1) *Context*. Contextual elements related to the customer’s history and trust in the partner company may influence the submitted bid. In addition, features of the case (e.g., public, or private market) also need to be considered.
- (2) *TS*. The TS consists of sub-assemblies and physical components of a harbor lifting device to which services such as training are added. A harbor lifting device is composed of an electrical distribution part, a remote-control part, and four to eight movements. The electrical distribution part consists of one to two transformers and one generator group is optional. The control part is characterized by the number of programmable logic controllers (PLC) and the number of human-machine interfaces. For each PLC, the type and function must be identified. For each movement, there are 1–4 dimmers and 1–30 engines. There can be 0–3 brakes per engine.
- (3) *DP*. The DP is composed of seven activities, seven activities to produce and deliver the harbor lifting device (*functional analysis, electrical part study, procurement, manufacturing, shipping, and commissioning*), and one activity of training.
- (4) *KPI*. When developing a bid, the company seeks to evaluate the cost of the TS to propose a price to the potential customer. Therefore, cost, price, and margin indicators will be used.

In addition, some bids include late penalties if the TS is not delivered within the allotted time. Duration indicators are therefore also chosen to characterize the DP.

Then, the *Business rules identification* is done. These rules link the parts of the bid described previously. For confidentiality reasons, we present here only a small number of business rules.

- *r1*. In the case of AC motors, a component must be added for the evacuation of energy and the expert must choose the technology of this component.
- *r2*. The number of engines per movement depends on the type of movement (vertical or horizontal).
- *r3*. The dimmers power depends on the engines power.

Finally, the elements presented previously were validated during a meeting with the knowledge expert, international coordinator, and OPERA expert. The different parts of a bid (context, TS, DP and KPI) were presented, discussed, and validated.

(2.3) *Modelling bids*. Concepts and variables are associated to each part of the model, thanks to the elements collected in activity (2.2). The set of concepts identified here will be structured in a taxonomy during next activity.

- (1) *Context*. One to four concepts are chosen between the four generic context concepts proposed in the generic model. The concept *Internal environment* is not useful for the company: only the concepts *Customer characteristics*, *Characteristics of the Call for tenders*, and *External environment* will be used. In addition, eight variables have been identified to characterize the context. Each variable is associated to one of the context concepts.
- (2) *TS*. A concept is associated to each family component. Fourteen concepts have been identified regarding the TS: *Harbor lifting device*, *Electric distribution*, *Remote control*, *Movement*, etc. A three-level product architecture or bill-of-materials (BOM) describes the TS (Fig. 3). However, if necessary, new artifacts could be added at all the levels of the BOM. Each component at each level of the BOM is described by one to several variables. Two variables characterize the higher level (harbor lifting device). In addition, 17 variables characterize the components, modulo the number of components.
- (3) *DP*. A concept is associated to each activity. Seven activity concepts corresponding to the activities listed previously were identified: *functional analysis*, *electrical part study*, *procurement*, *manufacturing*, *shipping*, *commissioning*, and *training*. Fig. 4 illustrates the DP associated to the TS. No variables characterizing this DP was identified. Indeed, the key point lies in the duration of each activity, which is an indicator. The choice of resources is not critical for the company and does not have to be identified during the bidding process.
- (4) *KPI*. Six indicator concepts corresponding to the indicators listed previously were identified: *Cost*, *Price*, *Margin*, *Load*, *Duration*, and *Confidence*. Variables are therefore linked to each part of the bid for each indicator concerned:
 - Regarding the TS, each level of the BOM is characterized by a cost variable, price variable, and confidence variable.
 - Regarding the DP, each activity is characterized by five indicators: a cost variable, price variable, load variable, duration variable, and confidence variable.
 - The bid itself (at the highest level) is characterized by the five previous indicators, as well as a margin indicator.

Second activity is *Knowledge bases structuring*. As mentioned earlier, the knowledge bases are composed of (1) a taxonomy, (2) a CSP approach, and (3) a past cases base. The concepts identified in previous activity are organized using a taxonomy (Fig. 5). Regarding the CSP,

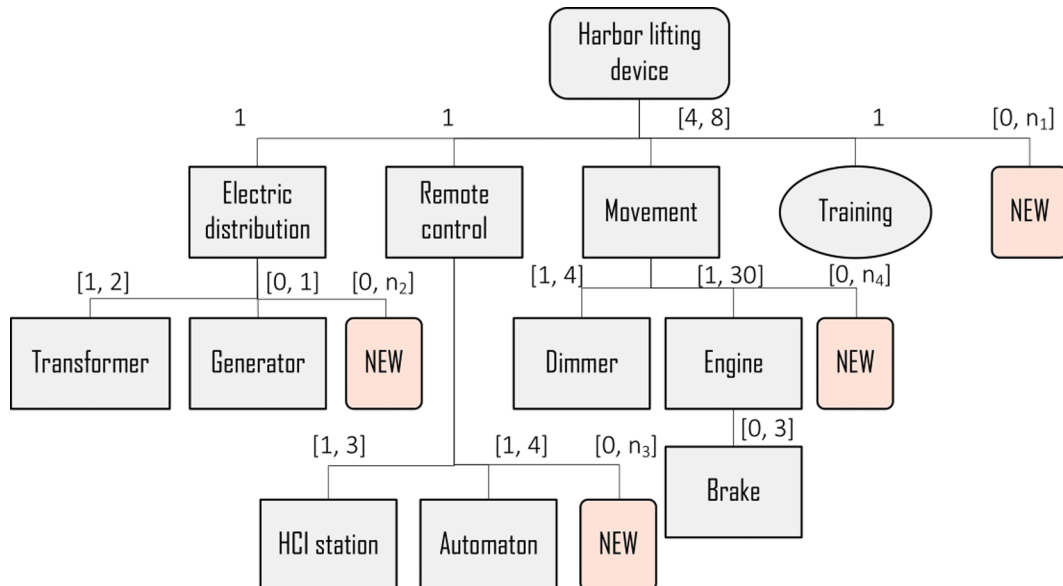


Fig. 3. Specific technical solution for the case study.

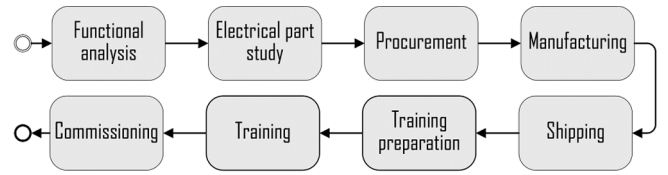


Fig. 4. Specific delivery process for the case study.

several constraint structures have been identified:

- 13 constraints concern the TS,
- 2 constraints link context to another part of the bid,
- and several others explain how to calculate the KPI.

Finally, the case base structure is identified. Each of the CSP variable is a column descriptor of the case base.

All the modelling elements from the previous activities have been validated formally by the knowledge expert using a paper deliverable.

(2.4) *Populating knowledge bases*. Three activities are done:

- (1) *Constraints formalization*. The business rules identified in activity (2.2) are formalized as constraints. The structures of these constraints (links between variables) were previously identified during activity (2.3). We present here only the business rules presented previously. The business rule *r1* can be formalized as an activation constraint; the variable *Energy evacuation technology* is inactive by default. It is active if and only if the variable *Engine technology = alternative*. The business rule *r2* can be formalized as two compatibility constraints (Tables 2 and 3). The business rule *r3* can be formalized as a compatibility constraint (Equation (1)). Other constraints have been formalized on the other parts of the model; however, they will not be detailed here.

$$Power_{dimmer} \geq \sum Power_{engines} \quad (1)$$

- (2) *Past cases formalization*. Two past cases were formalized using the case base structure identified previously. The filling of the case base has allowed to instantiate the specific model on two given past cases, and thus, to validate both the generic model and the specific model.

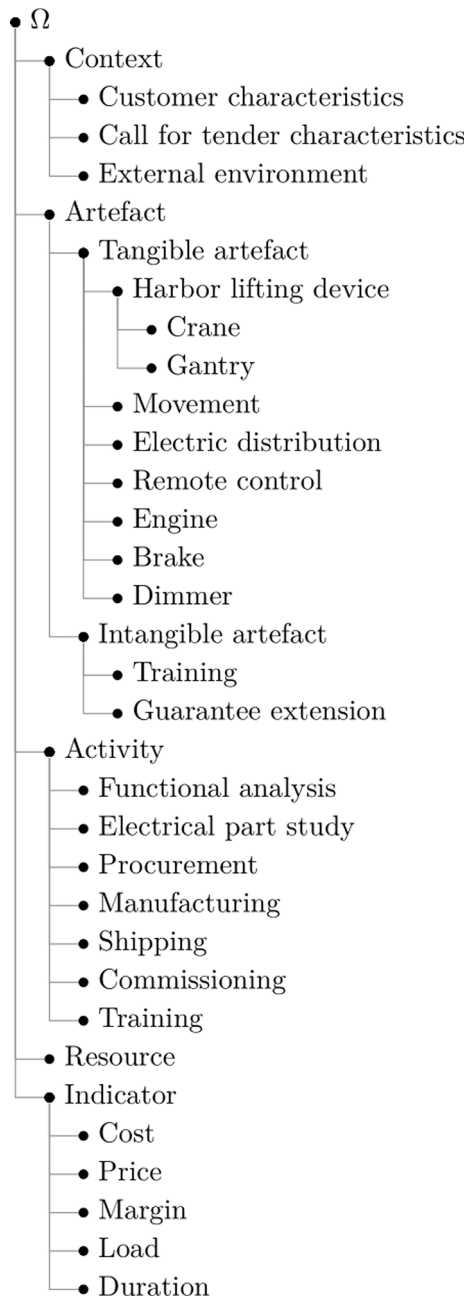


Fig. 5. Taxonomy for the case study.

Table 2
Compatibility table between variables “Movement name” and “Movement Type”

Movement name	Movement type
direction / orientation	horizontal
translation	horizontal
lifting	vertical
luffing	vertical

(3) *Model consolidation.* Several iterations have allowed to lead to the previous model.

4.3. Deployment of phase 3 – Implementation

The use case specific to the company resulting from the previous step

Table 3
Compatibility table between variables “Movement Type” and “Dimmers number”

Movement type	Dimmers number
horizontal	1
horizontal	2
horizontal	3
vertical	1

has been implemented in OPERA KBS. The concepts, variables and constraints have been implemented, as well as the structure of the past cases base. Fig. 6 and Fig. 7 illustrates an example of concepts and variables once implemented. Two past cases have been implemented in the OPERA KBS.

Several training sessions have been organized during the project and the company’s experts are now able to use the software properly. Concerning the (3.4) *Update of bid response process*, as the software is not yet used to elaborate new bids, the activity has not been achieved yet.



Fig. 6. OPERA interface of the taxonomy.

Variables associated with the concept ?					
Variable	Constraints ?	Domain	Visibility	ALL ?	↓ ALL ?
SYSTEM / cost (€) [KPI]	C+	[0, 1e+06]	<input checked="" type="checkbox"/>	⌵	↓
SYSTEM / trust (-) [KPI]	C+	green yellow red	<input checked="" type="checkbox"/>	⌵	↓
SYSTEM / Prix [KPI]	C+	1e+06	<input checked="" type="checkbox"/>	⌵	↓
SYSTEM / Qualité	C+	1 2 3	<input checked="" type="checkbox"/>	⌵	↓
SYSTEM / duration (jour) [KPI]	C+	0	<input type="checkbox"/>	⌵	↓

Fig. 7. OPERA interface for variables associated to a given concept - Example of “System” concept.

4.4. Deployment of 4 – Exploitation and 5 - Maintenance phases

The OPERA KBS have just been developed. Although it has been validated by the company, the *Exploitation* and *Maintenance* phases are just beginning. This start looks promising and we are waiting for first feedbacks following deployment and exploitation.

4.5. Case study synthesis

At the end of the deployment of the methodology, the company-specific bid model has been developed. The sales manager, who played the role of the knowledge expert, and the person responsible for international relations, who played the role of the future user of the KBS, have been strongly involved to achieve this model. A total of 25 concepts were identified to characterize the different parts of the bid. These concepts are structured in a taxonomy illustrated Fig. 5. A total of 42 variables, modulo the number of components, are associated with these concepts. Thanks to the instantiation of the company-specific model on two past cases, we were able to validate not only this model, but also the generic one, from which the specific model has been developed. The development of a bid (instantiated model) can be achieved both from the generic or from the specific model. However, the company will promote the use of the specific model because it is customized to its needs and thus easier to use.

5. Results and implications

As we mentioned in Section 2, to the best of our knowledge, there is no methodology dedicated to the deployment of KBS in the bidding process context. This section is about the OPERA KBS deployment in companies, but, from our point of view, it is not relevant to directly compare our methodology with those presented in Section 2 because they do not deal with the same object of study. Thus Section 5.1 is a synthesis of the results of deployment tests on three other companies (in addition from the one used as a case study in the previous section) as part of the OPERA project. Section 5.2 presents managerial and methodological implications about the OPERA KBS deployment in companies.

5.1. Results from application in different companies

Within the framework of the OPERA project, the OPERA KBS software and the ISiEM methodology were deployed in four different companies:

- A small enterprise (less than 20 employees) designing harbor lifting device, which was the subject of the case study presented in Section 4. This company mainly responds to “product” oriented bids, often with a non-negligible proportion of “service” (training, maintenance, etc.).
- A medium-sized company (approximately 150 employees) designing special cutting: this company responds almost exclusively to “pure product” bids.
- A small consulting company (less than 50 employees): this company responds exclusively to “service” bids concerning training or continuous improvement.
- A large service company (more than 10,000 employees): this company responds exclusively to “service” bids concerning for instance dimensioning or numerical modelling studies.

The diversity of the companies that participated in the deployment of OPERA KBS made it possible to validate the bid model presented in Fig. 1 to represent bids concerning all types of products, services, or PSS (Guillon, et al., 2021). Moreover, the methodology detailed in this article has been validated by very different companies, in terms of sizes, organizations, and kind of calls for tenders to which they respond, thus demonstrating the robustness of the proposed approach.

From an operational point of view, OPERA KBS has been developed in parallel with its deployment in partner companies using an agile and user-centered approach. All OPERA KBS’s design activities, from the definition of specifications to computer programming and functional validation, have been the subject of numerous iterations between developers, user companies, and the team in charge of supporting its operational deployment. Over a period of almost four years, more than 40 meetings were held to express and validate the expectations of each partner company on an individual basis. These different working sessions with each company have resulted in:

- a “paper” model for each company, containing their specific knowledge models (result of the Phase 2 - *Specialization*)
- a dedicated software application for each company (result of the Phase 3 - *Implementation*)

In addition, around ten workshops bringing together all the stakeholders allowed to combine and generalize the individual issues to design a generic model and a generic methodology. Finally, all the tests carried out have helped to improve and make OPERA KBS more reliable so that it can best meet the needs of final users.

Moreover, during a final workshop where the companies implemented their use cases in the latest version of the OPERA KBS, a survey was conducted to collect user opinions on OPERA KBS and its operational implementation. The results show that, despite a significant time investment to get used to the software, companies are satisfied because OPERA KBS allows them to standardize, improve and make their responses to calls for tenders more reliable while considering data (particularly contextual data or data linked to the delivery process) that were not previously considered. However, they note a need to make their existing bidding processes evolve.

5.2. Managerial and methodological implications

Like any knowledge management approach, the proposed methodology is very time consuming and requires a strong involvement of industrial stakeholders to be effective and relevant (Gupta, Iyer, & Aronson, 2000; Hansen, Nohria, & Tierney, 1999). Indeed, to realize the case study presented in Section 4 and implement the methodology detailed previously, we need to spend more than two weeks with the expert (sales manager) and the technical user (international relationships coordinator) of the company, whose one week of work dedicated to interviews about the case study, and to make four iterations to consolidate and validate the model. The motivation and availability of stakeholders are therefore critical factors for the success of this approach, and they must be anticipated before starting. Thus, we recommend an exterior accompaniment. This methodology can be used by consulting companies, project managers or scientists wishing to be part or manage the accompaniment project.

However, the implementation in real conditions of our methodology in the case study highlighted areas for improvement that will have to be formalized and validated in future work. For example, step (2.2) of the methodology, which concerns the identification of the bid elements, stipulates that it is possible to study the different elements (TS, DP, context, KPI) in parallel. However, our experience leads us to recommend starting with the TS part for companies making industrial products to focus on the expertise of the company. Then, once the actors are involved and familiar with the method, the DP part and the *Context* part can be studied. For service companies, we recommend starting with the DP part.

6. Conclusion and future scopes

The bidding process is a major challenge for companies involved in this commercial approach, which must convince potential customers of their ability to produce an attractive product, not only from a functional point of view but also in terms of costs and delivery time. In this difficult and competitive environment, a KBS could assist actors involved in the bidding process to develop a bid technically relevant, financially competitive, and by minimizing risks. Such a KBS is based on a generic bid model (Guillon, et al., 2021) and on generic knowledge bases. A taxonomy allows to structure the knowledge, a CSP approach allows to model business rules, and a CBR approach allows to reuse the knowledge of past bids.

The OPERA KBS proposes to actors the following functions to develop a bid: (1) implement the different elements of the specific bid model (context, TS, DP, risks, and KPIs), using taxonomy, CSP rules, and

case base; (2) control the coherency of the current bid based on CSP rules; (3) verify bid relevancy by integrating KPIs; (4) reuse subsets of past bids to integrate them into the current bid, (5) define strategies for minimizing risks. The companies involved in the OPERA project have validated this approach. Besides, using the OPERA KBS, companies expect both (1) to spare time for building first and relevant bids and (2) to get more original possibilities by exploiting past bids.

To the best of our knowledge, there is no existing method to define and set knowledge bases with knowledge relative to CSP and CBR associated in the same and homogeneous system. Moreover, recent works focus mostly on technical aspects and very little deal with methodological aspects. The ISIEM approach is intended to cover the gap between the development of a necessarily generic knowledge-based system and its deployment that can only be company-specific. It covers all the phases discussed in the survey but distinguishes itself by the fact that the KBS is a prerequisite: the objective of ISIEM is to adapt OPERA KBS to the company and to support the company transformation. We illustrate ISIEM methodology through a case study built in partnership with an industrial company manufacturing harbor lifting devices. The specific OPERA KBS for this company has been configured and next step is to focus on the bidding process transformation caused using this new system. This point has not been studied yet and the proposed ISIEM methodology, which is knowledge-centered, should integrate change management activities to help actors' empowerment, and become a complete business process re-engineering methodology.

In addition, several research axes are crucial before implementing OPERA KBS in a company. OPERA KBS framework is based on the definition of solutions modelled as a product, service, or PSS. Over the last decades, products have become complex, and most are considered now as cyber-physical systems (Guérineau, Bricogne, Durupt, & Rivest, 2016), due to the development of electronics components and embedded software (Ullman, 2010) and IoT capabilities (Pannaga, Ganesh, & Gupta, 2013). Many companies are switching from a product-centric vision to a service-oriented vision, or even to smart services vision through a servicization process (Baines, et al., 2009). By considering smart PSS (Chowdhury, Haftor, & Pashkevich, 2018; Pirola, Boucher, Wiesner, & Pezzotta, 2020) as a PSS embedding digital technologies, based on connectivity and cloud capabilities, OPERA KBS generic bid model should be extended to be able to capture such new capabilities.

Considering OPERA KBS reliability, the system has been tested in a limited context, with few users and without confidential data. System robustness must be explored as well as data privacy and cybersecurity challenges evaluated and studied, especially if the company plan to involve users from different geographical places and/or users from its potential customers. For example, in this context, the integration of blockchain technology such as in (Harish, Liu, Zhong, & Huang, 2021) for managing exchanges between the different stakeholders of a bidding process may bring tools for strengthen transactions and reduce risk.

CRedit authorship contribution statement

Delphine Guillon: Investigation, Writing – original draft, Writing – review & editing. **Eric Villeneuve:** Investigation, Writing – original draft, Writing – review & editing, Supervision. **Christophe Merlo:** Writing – review & editing, Funding acquisition. **Elise Vareilles:** Writing – review & editing, Funding acquisition. **Michel Aldanondo:** Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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