To link to this article : DOI : 10.1080/00207543.2017.1353156
URL : http://dx.doi.org/10.1080/00207543.2017.1353156

To cite this version : Sylla, Abdourahim and Vareilles, Elise and Coudert, Thierry and Kirytopoulos, Konstantinos and Aldanondo, Michel and Geneste, Laurent *Readiness, feasibility and confidence: how to help bidders to better develop and assess their offers.* (2017) International Journal of Production Research, vol. 55 (n° 23). pp. 7204-7222. ISSN 0020-7543

Readiness, feasibility and confidence: how to help bidders to better develop and assess their offers

Abdourahim Sylla[a,b]*, Elise Vareilles[a], Thierry Coudert[b], Konstantinos Kirytopoulos[c], Michel Aldanondo[a] and Laurent Geneste[b]

[a]*CGI, Université de Toulouse/Mines Albi, Albi, France;* [b]*LGP, Université de Toulouse/ENI Tarbes, Tarbes, France;* [c]*School of Mechanical Engineering, National Technical University of Athens, Athens, Greece*

(*Received 21 November 2016; accepted 2 July 2017*)

In a bidding process, the bidder must define and evaluate potential offers in order to propose the most suitable one to the potential customer. Proposing attractive but also realistic offers to various potential customers is a key factor for the bidder to stay competitive. In order to achieve this, the bidder needs to be very sure about the technical specifications and the constructability of the proposal. However, performing a detailed design is resource and time-consuming. This article proposes the foundation of a new framework which can help bidders to define the right offer: (i) in the context of a non-routine design process, while avoiding a detailed design and (ii) taking into account two new indicators that reflect the bidder's confidence that they can meet the commitments once the offer is accepted. The first indicator (OCS) characterises the Overall Confidence in the technical System, while the second one (OCP) gives the Overall Confidence in the delivery Process. Both OCS and OCP are based firstly on two factual objective indicators, Technology Readiness Level (TRL) for OCS and Activity Feasibility Level (AFL) for OCP, and secondly on two human-based subjective indicators, Confidence In System (CIS) for the OCS and Confidence In Process for the OCP. An illustrative application shows how this framework can really help bidders define an offer, while avoiding detailed design and enable them to evaluate the confidence level in each potential offer.

Keywords: product configuration; knowledge management; readiness; feasibility; confidence

1. Introduction

1.1 *Research background*

Today's global economy generates ever-increasing competition in allsectors of the economy. One main contributing factor is the advancement of web technologies that enable customers to link with and rapidly consult a wide range of potential suppliers. As a result, the traditional stable customer/supplier relationship is becoming less dependable. Instead customers easily hold multiple consultations with different suppliers and usually choose the one best-suited to their requirements through a competitive bidding process. As explained by Huang and Mak (2000), competitive tender/bidding can be adversarial, undermining collaborative partnerships or relationships. Therefore, from the bidder's side, the problem arises of defining and selecting the most suitable offer to submit to a potential customer (Leopoulos and Kirytopoulos 2004). Bidders have now to choose their final offer based on the technical system's functional specifications as well as their skills, strengths and capabilities to deliver it.

In this article, we consider situations where the offer definition involves some design activities and we enhance the process from the bidder's perspective. We assume that an offer is composed of two items, namely: (1) a technical system (Bill-of-materials describing the system composition) and (2) its delivery process (Set of activities used to produce and implement the technical system once the offer is accepted). A similar definition has previously been used in Kroemker et al. (1997). Considering these two items when elaborating an offer enables the bidder to better quantify the cost and the duration of the delivery process. Most of the time, the details of the delivery process are not provided to the customer. These two items (technical system and delivery process) are simultaneously designed with various levels of detail and evaluated in order to allow the bidder to select the best solution to submit.

Design is a creative activity, starting from the expressed requirements and the existing knowledge, that leads to the definition of a system and a process that together satisfy these requirements (Suh 1990; Ulrich and Epinger 2016).

---

*Corresponding author. Email: abdourahim.sylla@mines-albi.fr

The notion of knowledge in the definition is very important for design activities and thus, for the offer definition and selection in the bidding process. Based on available knowledge of: (i) the domain (range of acceptable solutions), (ii) the artefact to be designed (technical system, delivery process or both) and (iii) the design approach and requirements, Brown and Chandrasekaran (1985) have classified design into three categories: (i) routine design, (ii) innovative design and (iii) creative design. In the context of a bidding process, we consider that the offer definition can vary from a very routine design to an innovative one.

While, defining an offer in the case of non-routine or innovative design, two different approaches can be used by bidders. The first approach relies on a detailed design of the solution for both the technical system (a 'deep' bill-of-materials with selection of lower level components) and its delivery process (the manufacturing activity list to be carried out with pre-allocation of human and machine resources). Thus, uncertainties are low and the confidence that the final designed and implemented technical system will fulfil all customer expectations (performance, cost and delivery time) is high. However, this approach is time- and resource-consuming and there is no guarantee that the offer will ultimately be accepted. On the other hand, the second approach consists only in clarifying and choosing the main ideas or key concepts in the technical system (a 'shallow' bill-of-materials with selection of technologies) and its delivery process (key activities list with identification of key human and machine resources). This helps avoid the detailed design, but uncertainties can be high and confidence low.

A way to avoid the entire detailed design, while mastering uncertainties, is to be aware of the confidence level in the main ideas or key concepts (system technologies, macro-activities and key resources) of the potential offers. Thus, when comparing different potential offers on the mainstream criteria (performance, cost, resources allocation and delivery time), the bidders can modulate their judgments with respect to confidence quantification and select the most appropriate offer. To this end, the contribution developed in this article is to propose a knowledge model and the relevant confidence metrics for offer elaboration, taking into account simultaneously the technical-system side and the delivery-process aspect.

1.2 *Models and tools for aiding system and process design at the bidding process*

In the context of routine design, the knowledge of the domain of the object to be designed, the design approach and the requirements are all available (Brown and Chandrasekaran 1985). All that remains is to choose or adapt a solution or solution principles relevant to the requirements. The extreme case of routine design is configuration or customisation (Felfernig et al. 2014). In this case, it is assumed that all the knowledge needed to describe all possible and acceptable solutions for the technical system and the delivery process is available. For 20 years now, knowledge-based configuration software has been recognised as a very efficient tool for aiding system and process definition in the context of configuration (Felfernig et al. 2014). The level of uncertainty in the offer characteristics in this context is rather low and the bidder's confidence that the final designed and implemented technical system will match customer's expectations (performance, cost and delivery time) is rather high. On the other hand, when we move towards innovative design, new solutions that require further design and engineering activities have to be defined and carried out. Therefore, the uncertainties in the offer attributes are more important and the confidence that the final designed and implemented technical system will match customer's expectations is lower.

Several research projects have been undertaken in order to propose models and tools for aiding system and process design, especially knowledge-based systems (ontology, constraint-satisfaction problem, case-based reasoning, expert system, etc.) (Vareilles et al. 2012). Felfernig et al. (2003) and Romero Bejarano et al. (2014) proposed a methodology based on ontology and associated inference techniques for the configuration problem. Mida and Vernadat (2009) and Barták, Salido, and Rossi (2010) presented a constraint-satisfaction problem or CSP approach for process planning and scheduling. Aldanondo and Vareilles (2008) and Zhang, Vareilles, and Aldanondo (2013) explained how the concurrent configuration of a product and a process can be considered as a single constraint-satisfaction problem.

Considering the specific case of a bidding process, several research works have been dedicated to the bid/no bid decision-making problem and the bid mark-up size estimation, especially in the field of civil engineering (Lin and Chen 2004; Dikmen, Birgonul, and Gur 2007; Shokri-Ghasabeh and Chileshe 2016). However, only a few projects or articles have tackled the definition of the technical system and its delivery process in non-routine design situations with consideration of the confidence issues. In the Tender Support System (TSS) project, Vanwelkenhuysen (1998) developed an expert system to support the offer elaboration of industrial centrifugal pumps. The main objectives were to reduce the offer preparation time and to increase the scope of the standard technical solutions. In the BIDPREP project (Kroemker et al. 1997; Kromker 1998), a reference model and a computerised system were developed to support the bid-preparation process. The BIDPREP model is process-oriented, based on concurrent engineering concepts. The set-up of the technical solution is supported by a product modeller that, given (i) customer's requirement specifications (ii) information from bidder suppliers and (iii) existing solutions, generates technical-system solutions and delivery-process plans. In the European-funded project DECIDE (DECIsion support for optimal biDding in a competitive business Environment), a methodology and decision-support tools were proposed for the definition of the technical solution relevant to an offer and the calculation of its cost (DECIDE 1998). The European project PRiMA (Project Risk MAnagement) has also provided methods and tools to capitalise, estimate and manage risks in the bidding process. Its originality lies in the consideration of internal and external risks, but also in the implementation of the approach in an Interactive Decision-Support System (PRiMA 2002).

As reported above, several approaches and models have been proposed for aiding the product and process configuration in routine design situation. These models are at the basis of our proposals. Some research projects clearly consider technical-system and delivery-process definition in the bidding process. A common point of these research projects is that the solutions are defined with a strong knowledge support and that the confidence issue is not addressed. Some research works focus on risk management in the bidding process and mainly deal with the bid/no bid decision problem and bid mark-up size estimation. Therefore, in this article we propose a new framework, extending knowledge-based configuration approaches, which can help the bidder to define an adequate offer (technical system and delivery process), not only for routine but also non-routine design situations, with a confidence characterisation of the potential offer solutions.

1.3 *Research aim*

As mentioned above, the aim of this article is to lay the foundation of a new framework which can help bidders to better define the right offer, taking into account new indicators that reflect their confidence. These new indicators characterise the overall confidence in the technical system (OCS) and in its delivery process (OCP). The overall confidence provides the bidder with a measure of the ability of the technical system and delivery process relevant to the offer to fulfil all customers' expectations (performance, cost and delivery time) after its design and its implementation. In the proposed framework, two kinds of indicators are used to compute the overall levels of confidence. The first kind is based on facts and effective observations, while the second kind is based on human judgement and subjective feelings. These two kinds of indicators characterise the technical system and the delivery process, providing four indicators. The decision-support tool, for (i) the design of technical systems and delivery processes, (ii) their assessment in terms of both standard indicators and overall offer confidence, relies on filtering methods within the constraint-satisfaction problem framework. The very first ideas about the confidence metric were published in Sylla et al. (2017).

The rest of the article is organised as follows. In Section 2, the main ideas about concurrent configuration of system and process are recalled. The Constraint-Satisfaction Problem (CSP) framework that supports the proposed decision-aiding tool is also explained. In Section 3, the metrics of the overall confidence in a technical system and its delivery process are defined and discussed. In Section 4, we explain the proposed approach through an illustrative application dealing with a crane offer.

2. Configuration of systems and delivery processes

In this section, we first recall the concurrent configuration of system and process in routine situations. Then, the formalisation of the concurrent configuration of system and process as a CSP is presented and adapted to handle non-routine design. In order to synthetise our proposals, a single level of decomposition is assumed: system/sub-systems and process/activities.

2.1 *Concurrent configuration in routine situations*

When dealing with concurrent configuration of product and process, (Mittal and Frayman 1989; Aldanondo and Vareilles 2008; Zhang, Vareilles, and Aldanondo 2013) have shown that the product can be considered as a set of components and its delivery process as a set of production activities.

According to the customer's expectations, the configuration of a product is achieved either by selecting components in component families (such as an engine in a catalogue) or by choosing values of descriptive attributes (such as the power of an engine, or the stiffness of a jib), as shown by the dotted boxes in the left part of Figure 1. Of course, not all combinations of components and attribute values are allowed (a high-power engine is incompatible with a low-stiffness jib). Thus, as explained by many authors, including Sabin and Weigel (1998) and Soininen et al. (1998), product configuration can be considered as a discrete constraint-satisfaction problem (CSP), where a variable is a component family or a descriptive attribute and constraints (solid line in the left part of Figure 1) specify acceptable or

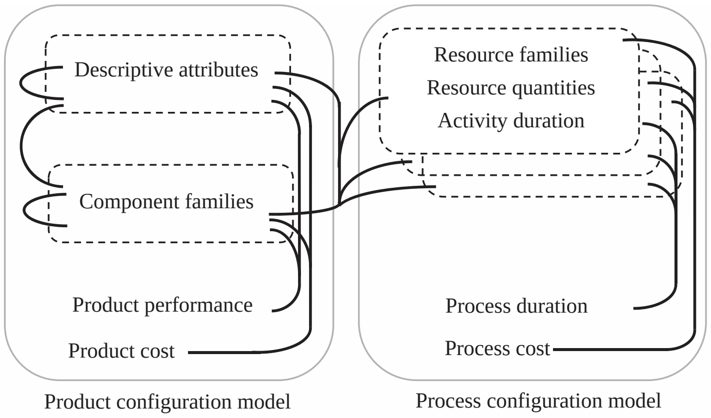


Figure 1. Concurrent configuration of product and process.

forbidden combinations of components and attribute values. Some kinds of product performance indicators can characterise the product, thanks to some mixed constraints (symbolic and numerical domains) that link the most important product features. For example: the performance of a crane is a function of its engine power and its tower height.

For process configuration, a similar approach is proposed by Zhang, Vareilles, and Aldanondo (2013) and Pitiot, Aldanondo, and Vareilles (2014). According to the configured product features (selected components and attributes values), the resources for each production activity can be selected in families of resources (a small assembly table for a small crane engine is chosen in the list of assembly tables), and in some cases a quantity of resource can be specified (2 operators for a large crane, 1 for a small one). Of course, selected components and values (for products) and selected resources and quantities (for activities) impact activity durations and therefore, affect the delivery-process duration or cycle time. For simplicity, we assume that the delivery process is a sequence of activities and therefore, that the process duration equals the sum of the activity durations. As for products, process configuration can be considered as a CSP, where each activity gathers variables corresponding to resource families, resource quantities and activity duration. Constraints (solid line in the right part of Figure 1) restrict possible associations.

For both product and process, all variables can be linked to cost indicators (one for product and one for process) again with mixed constraints in order to obtain a global cost. With the previous problem descriptions, Pitiot, Aldanondo, and Vareilles (2014) and Pitiot et al. (2012) have suggested (i) combining these two problems into a single one and (ii) considering this concurrent problem as a single CSP. Viewing this concurrent configuration problem as a single CSP allows propagation or constraint filtering mechanisms to be used as an aiding tool. Each time a customer's expectation is added (mainly for the product side), constraints propagate this decision and prune variable values for descriptive attributes, component families, resource families, resource quantities, activity duration, after which product performance, process delivery time and global cost can be updated. For a detailed presentation with an easy-to- understand example, we suggest consulting (Pitiot, Aldanondo, and Vareilles 2014).

This kind of problem modelling is the ground basis of configuration problems. All commercial websites and conventional configuration software packages that run interactive configuration or customisation processes rely on such problem models. Of course, propagation and solving approaches can be very different. The key point is that all possible solutions have been studied in advance, meaning that all component families and relevant components, all attributes with their possible values, all process activities with their resource families and resources have been analysed and qualified before operating the configuration system. This is the case for websites offering cars, computers, bicycles, kitchens. Thus, the configuration process is 'entirely routine' and there is absolutely no design or creative task. For example, even a child can configure a car on the Renault car configuration website without any knowledge of cars. In that case, when the customer validates a configuration, the detailed design of both product and process is generated almost automatically without any doubt or uncertainty. The resulting performance, delivery time and costs are accurately known. Thus, back in the case of a bidding process, the bidder has full confidence in his/her offer without any stress and knows for sure that he/she can, without any doubt, fulfil his/her commitments.

2.2 *Concurrent configuration in non-routine situations*

Our goal is to update the previous problem and solution in order to handle (i) technical systems instead of products and (ii) less routine situations.

Moving from products to systems is quite easy if we assume that: (i) a system is a set of sub-systems that may be linked to form the system architecture (ii) a sub-system is represented by a set of descriptive attributes and one family of technical solutions (equivalent to a component family in product configuration).

Moving to non-routine configuration is less obvious: it means that the bidder must undertake some design or engineering activities in order to satisfy the customer's expectations. The two following subsections propose some knowledge modelling updates in order to fulfil the previous expectation. From this point forward, we will only focus on configuration of technical systems (and not products) and delivery processes in non-routine situations.

2.2.1 *From a routine to a non-routine system configuration model*

On the technical-system side, two kinds of model modifications have been identified and need modelling updates: the definition of new sub-systems and new integrations of already existing sub-systems. A key point must be underlined; all the following new solution possibilities have to be identified, characterised and estimated beforehand by the system design department of the bidder, meaning that any out-of-range solution possibility must have been previously validated.

Case 1: at the sub-system level, a novel sub-system has to be designed to meet requirements. In this case, the variables that describe or identify the new sub-system must have their definition domains updated in order to allow a value 'out of range'. As new values have been added, it is necessary to update the set of constraints by adding new possible combinations of variable values and therefore, new tuples.

For example, let us consider that the sub-system jib of the crane system is a 'pure' configuration system (left part of Figure 2). Assume that until now, only four jib technical solutions (Ji_So_1, Ji_So_2, Ji_So_3, Ji_So_4) corresponding with two lengths (4 and 8 m) and two levels of stiffness (Ji_St_Low for the low-stiffness and Ji_St_Strong for the high-stiffness) have been already designed, manufactured and integrated in a crane and supplied to a customer. Now, if the bidder wants to satisfy a customer that requires a jib with high stiffness and a length different from 4 and 8, it is necessary to launch a non-routine design process and the model has to be updated. A set of possible values for the descriptive attributes jib_length (for example:]4, 8[U]8, 12[) and a new technical solution (Ji_So_New) in the family of jib technical solutions (right part of Figure 2) have to be added. In the two models of Figure 2, the solid lines represent allowed combinations with a discrete constraint (arity 3) linking the values of the descriptive attribute and the technical solutions (Jib_length, Jib_Stiffness, Jib_Solution).

Case 2: at the system level, a new system must be designed, composed of a novel integration of already existing sub-systems that have never been integrated together. In that case, there is a need to add a specific 'new value' in the definition domain of the system identification variable and a constraint tuple that identifies its composition in terms of sub-systems.

For example, let us consider two sub-systems, 'jib' and 'tower' of a crane system (left part of Figure 3). Each sub-system has two technical solutions: jib (Ji_So_1: 4 metres-length and low-stiffness, Ji_So_2: 4 metres-length and strong-stiffness); a tower (To_So_1: 5 metres-height and low-stiffness, To_So_2: 5 metres-height and strong-stiffness). Assume that the bidder has decided in the past that it was of no interest to offer customers a crane with a low-stiffness jib and strong-stiffness tower (Ji_So_1 and To_So_2). Therefore, studies relevant to integration, assembly processes or system tests have never been carried out for such a crane. Only three combination possibilities are proposed, as in the left part of Figure 3. However, if a customer requires the previous out-of-range combinations (Ji_So_1 and To_So_2)

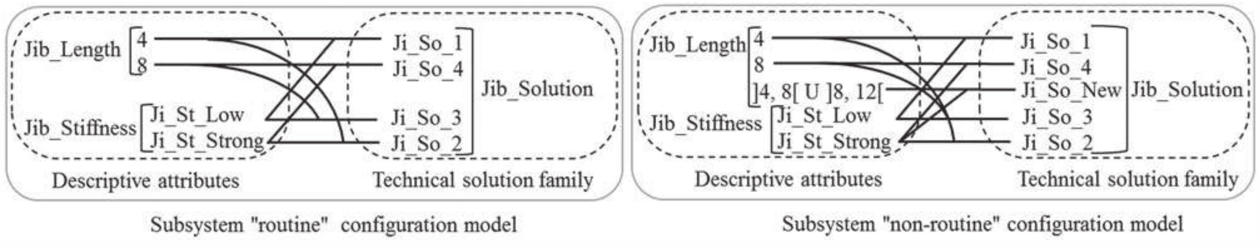


Figure 2. Configuration models for 'routine' and 'non-routine' situations with new sub-system.

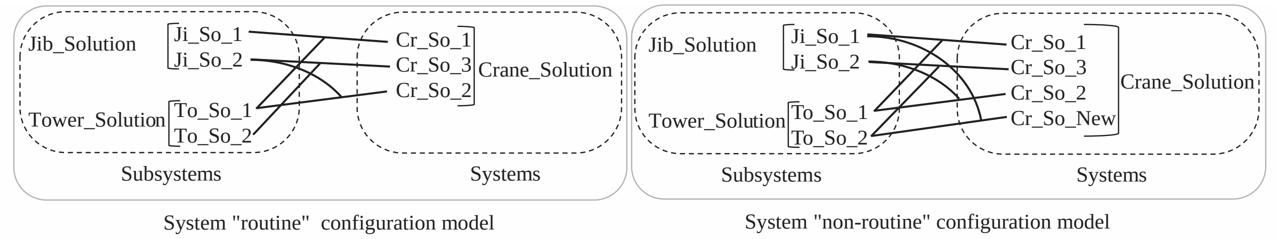


Figure 3. Configuration models for ‘routine’ and ‘non-routine’ situations with new integration.

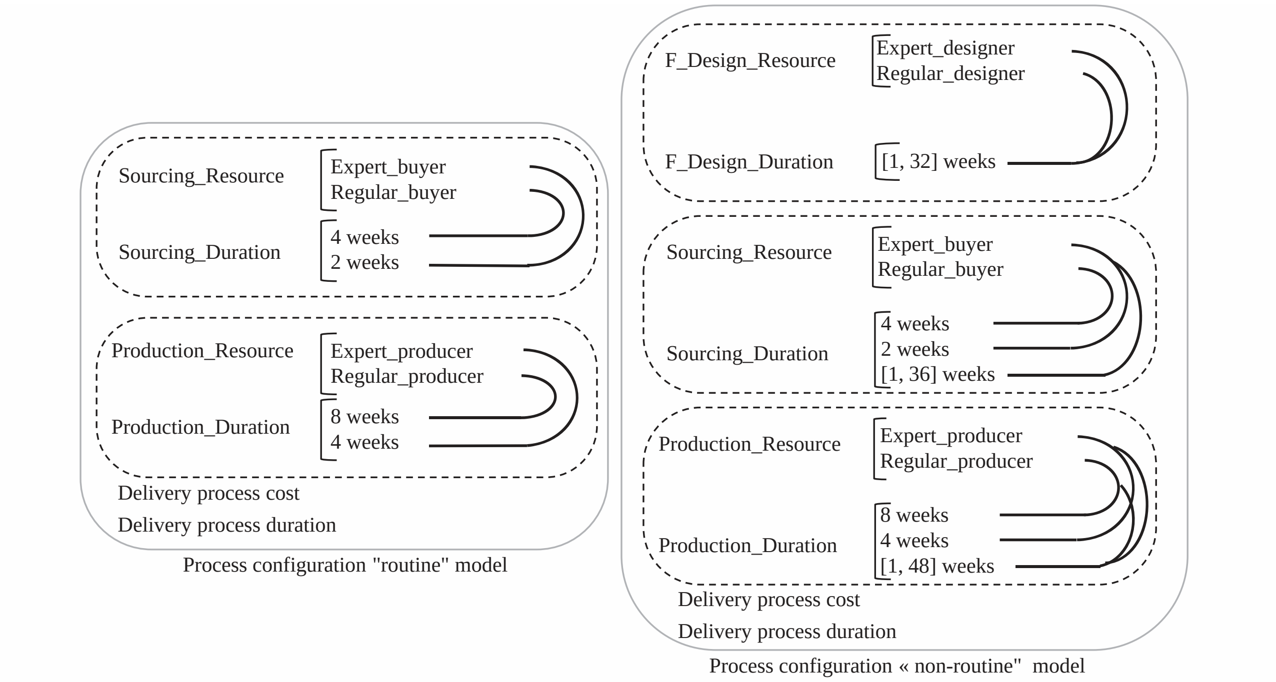


Figure 4. Configuration models of processes for ‘routine’ and ‘non-routine’ situations.

and if the bidder wants to keep the customer satisfied and ultimately allows this combination, the model should be updated with a new solution (Cr_So_new) and a new composition tuple, as shown in the right part of Figure 3.

Once the novel crane has been supplied to the customer, following the non-routine design process, and in order to capitalise this new knowledge, the complete model has to be updated by adding all the values related to this novel system. This update is essential to maintain an up-to-date systems catalogue for future bids.

2.2.2 *From a routine to a non-routine delivery-process configuration model*

On the delivery-process side, two kinds of modifications have also been identified: new activities and new activity parameter values. As for the system model, all useful updates must be validated by the delivery-process department of the bidder.

Case 1: a new activity is needed in the delivery process. As some design or engineering activities are necessary for non-routine situations, it is necessary to add an optional design or engineering activity in the delivery process.

For example, in the previous jib-length modification example, once the customer has accepted the offer, it is necessary to finalise the design of the technical system and its delivery process. Thus, if a new solution is necessary on the technical-system side, a new design activity must be added to the delivery process. In Figure 4, the left part shows a two-activity delivery process (Sourcing and Production), corresponding to the routine delivery process, whereas the right part shows a three-activity process, less routine, including an activity of finalising the design (F_Design), corresponding to the non-routine one.

Case 2: as at least one sub-system or system integration is novel, the definition domain of the parameters describing each activity: resource used, quantity of allocated resources, activity cost and duration may be updated.

For example, the left part of Figure 4 shows the resource parameters (two possibilities for each) and duration parameters (two durations for each) of each activity in a purely routine situation. Solid lines show the allowed combinations of values. In the right part of Figure 4, the definition domain of the duration of each activity has been updated with a new value defined with an interval ([1, max number of weeks]). For clarity, constraints (i) between technical system and delivery process (ii) computing delivery-process cost and (iii) computing delivery-process duration are not shown.

As for the system side, the delivery-process model has to be updated for each new accepted offer in order to capitalise and reuse knowledge for future bids.

3. Proposed method for offer confidence assessment

In Section 2, we have dealt with modelling issues for offer representation. This section describes the confidence metric proposals.

3.1 *Method framework*

As shown in Figure 5, each offer, composed of a technical system and its delivery process, is characterised by two new indicators: Overall Confidence In System (OCS) and Overall Confidence in Process (OCP). Each of them aggregates factual and objective indicators (System Readiness Level (SRL) and Process Feasibility Level (PFL)) and intangible and subjective indicators (Confidence In System (CIS) and Confidence In Process (CIP)). These indicators are evaluated for each sub-system of the technical system and for each activity of the delivery process.

In the following subsections, the metrics introduced above are defined and different aggregation mechanisms (i) between sub-systems and system (for readiness and confidence) and (ii) between activities and process (for feasibility and confidence) are presented and discussed. The method used to determine the OCS and OCP is also presented.

3.2 *Technical-system assessment*

3.2.1 *Technology, integration and system readiness level metrics*

Any system under development is composed of core technology components (or sub-systems) and their linkages, in accordance with the proposed architecture (Sauser et al. 2008). When developing a system, Henderson and Clark (1990) have showed the importance of knowledge on components and their integrations. These authors emphasised that when developing a technical system or integrating a sub-system into a technical system, attention should not only be paid to the sub-systems but also to their integration.

A technical system is structurally defined as a set of sub-systems that are integrated to form the system architecture. For the assessment of Overall Confidence of the System (OCS), a scientific literature survey has enabled us to identify a factual metric relying on the notion of Readiness Level (Sadin, Povinelli, and Rosen 1989; Mankins 1995; Sauser et al. 2008).

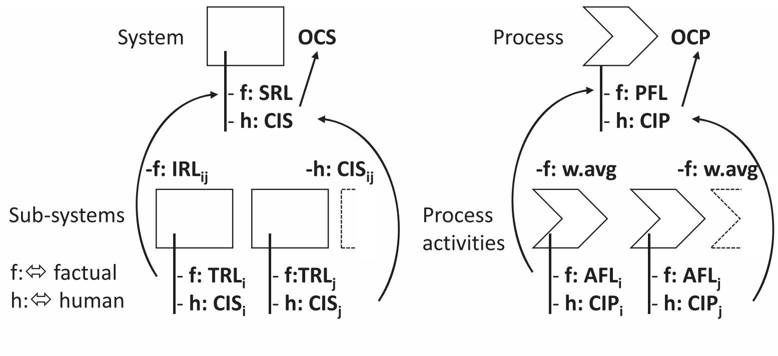


Figure 5. Characterisation of offers with confidence indicators.

The Technology Readiness Level or TRL is a systematic metric/measurement developed by Sadin, Povinelli, and Rosen (1989) and Mankins (1995) at the US National Aeronautics and Space Agency (NASA) for measuring the maturity of technologies. It has been used by industries and some US public organisations to take into account the uncertainties in the development of technologies (Mankins 2009; Magnaye et al. 2014). The TRL indicates how much a technology is ready to be used and deployed. The TRL is measured on a nine-level numerical scale (see left column of Table 1) (Tan, Sauser, and Ramirez-Marquez 2011). In our proposal, each sub-system$_i$ is characterised by a TRL$_i$.

The Integration Readiness Level or IRL$_{i,j}$ characterises the integration readiness level of a pair of sub-systems i and j. The IRL$_{i,j}$ indicates how much the integration of two technologies is ready for operation for a given function and is measured on a nine-level numerical scale (see right column of Table 1) (Sauser et al. 2008). In our proposal, each main interaction $_{i,j}$ between a sub-system$_i$ and a sub-system$_j$ is characterised by an IRL$_{i,j}$.

The System Readiness Level metric or SRL is computed as a function of TRL$_i$ and IRL$_{i,j}$. Since the notions of Integration Readiness Level (IRL) and System Readiness Level (SRL) (Table 2) were proposed (Sauser et al. 2008), the IRL and SRL scales have been accepted by several researchers. Several SRL calculation methods have been proposed, such as matrix algebra (Sauser et al. 2008; London et al. 2014) or tropical algebra (McConkie et al. 2013). The SRL calculation method proposed by Sauser et al. (2008) has been used by Magnaye, Sauser, and Ramirez-Marquez (2010) in a system development of a cost-minimisation model SCODmin, aimed at minimising system developmental costs. The US National Energy Technology Laboratory (NETL), Knaggs et al. (2015) also applied this SRL calculation method to estimate the readiness of two advanced fossil-energy technology projects.

In our proposal, we use the SRL calculation method proposed by Sauser et al. (2008). As explained in Sauser et al. ((2008) and Magnaye, Sauser, and Ramirez-Marquez (2010), the SRL calculation method uses a normalised matrix of pair-wise comparisons of TRL$_i$ and IRL$_{i,j}$ values. The IRL matrix and the TRL vector represent, respectively, the readiness levels of the potential integrations between two technologies and the readiness levels of these technologies. The IRL matrix is based on the following assumptions: for the integration of a technology with itself (IRL$_{i,i}$ = 9), if there is no integration between two technologies (IRL = 0) and IRL$_{i,j}$ = IRL$_{j,i}$.

$$[\mathrm{SRL}] = \begin{bmatrix} \mathrm{SRL}_1 \\ \mathrm{SRL}_2 \\ \cdots \\ \mathrm{SRL}_n \end{bmatrix} = \begin{bmatrix} \mathrm{IRL}_{11} * \mathrm{TRL}_1 + \mathrm{IRL}_{12} * \mathrm{TRL}_2 + \cdots + \mathrm{IRL}_{1n} * \mathrm{TRL}_n \\ \mathrm{IRL}_{21} * \mathrm{TRL}_1 + \mathrm{IRL}_{22} * \mathrm{TRL}_2 + \cdots + \mathrm{IRL}_{2n} * \mathrm{TRL}_n \\ \cdots \\ \mathrm{IRL}_{n1} * \mathrm{TRL}_1 + \mathrm{IRL}_{n2} * \mathrm{TRL}_2 + \cdots + \mathrm{IRL}_{nn} * \mathrm{TRL}_n \end{bmatrix} \tag{1}$$

Table 1. TRL scale & IRL scale.

Level	TRL	IRL
9	Actual system proven through successful mission operations	Integration is Mission Proven through successful mission operations
8	Actual system completed and qualified through test and demonstration	Actual integration completed and Mission Qualified through test and demonstration in the system environment
7	System prototype demonstration in operational environment	The integration of technologies has been Verified and Validated with sufficient detail to be actionable
6	System/sub-system model or prototype demonstration in relevant environment	The integrating technologies can Accept, Translate and Structure Information for its intended application
5	Component and/or breadboard validation in relevant environment	There is sufficient Control between technologies necessary to establish, manage and terminate the integration
4	Component and/or breadboard validation in laboratory environment	There is sufficient detail in the Quality and Assurance of the integration between technologies
3	Analytical and experimental critical function and/or characteristic proof of concept	There is Compatibility (i.e. common language) between technologies to orderly and efficiently integrate and interact
2	Technology concept and/or application formulated	There is some level of specificity to characterise the Interaction (i.e. ability to influence) between technologies through their interface
1	Basic principles observed and reported	An Interface between technologies has been identified with sufficient detail to allow characterisation of the relationship

Table 2. SRL scale.

Level	SRL	SRL value
5	Execute a support programme that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total life cycle	0.9–1.00
4	Achieve operational capability that satisfies mission needs	0.8–0.89
3	Develop a system or increment of capability; reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for producibility; esure affordability and protection of critical programme information; and demonstrate system integration, interoperability, safety and utility	0.5–0.79
2	Reduce technology risks and determine appropriate set of technologies into a full system	0.2–0.49
1	Refine initial concept. Developsystem/technology development strategy	0.10–0.19

Table 3. (a) Five levels of CISi and CISij, (b) Five levels of CIS of the system.

Values	Description
(a)	
5	Very high
4	High
3	Medium
2	Low
1	Very low
(b)	
0.9–1.00	Very high
0.8–0.89	High
0.5–0.79	Medium
0.2–0.49	Low
0.1–0.19	Very low

$$[\mathrm{SRL}] = \frac{\left(\frac{\mathrm{SRL}_1}{n_1} + \frac{\mathrm{SRL}_2}{n_2} + \cdots + \frac{\mathrm{SRL}_{\mathrm{n}}}{n_n}\right)}{n} \tag{2}$$

3.2.2 *Confidence in sub-systems (CISi) and system (CIS) metrics*

In the previous section, TRL, IRL and SRL were introduced as factual metrics to determine the readiness of a given technology or a system. As it can be seen through the different scales of these items, these metrics are assessed with general knowledge that is not company-specific. Therefore, in order to quantify the proficiency level in technology specific to the bidder, another confidence metric is necessary. This metric takes into account the feeling or subjectivity of the bidder about his/her ability to master a technology and his/her ability to use it with respect to all customer expectations (including performances and cost).

Therefore, for a sub-system with a defined readiness level, we propose a second metric named Confidence In Sub-system ($\mathrm{CIS}_{\mathrm{i}}$). $\mathrm{CIS}_{\mathrm{i}}$ corresponds to the bidder's feeling about the offer under construction and results of some fuzzy mental aggregation of the three following dimensions:

(i) Experience of the bidder of the considered sub-system technology. This represents his/her level of tacit and explicit knowledge gained through involvement in the design of a specific kind of sub-system.

(ii) Similarity between the considered sub-system and previously developed sub-systems. The similarity is the measure of the likeness between the sub-system under consideration and the other previously designed sub-systems.

(iii) Thoughts of the bidder about the considered sub-system. This represents the designer's guess regarding the success of the sub-system in satisfying customer's requirements.

We propose assessing the CIS_i metric with the five-level scale shown in Table 3(a).

A similar assessment is also proposed for the confidence in integration of each pair of sub-systems i and j CIS_{ij}. The previous aggregation method proposed by Sauser et al. (2008) is also used to calculate the Confidence In System metric (CIS). The scale used for this metric is presented in Table 3(b).

3.2.3 *Overall Confidence In System metric (OCS)*

At the system level, after the calculation of the SRL and the CIS, the matrix of Figure 6 is used to determine the OCS of the technical system. The OCS is ranked on a scale of nine levels (1 is the lowest and 9 the highest). Three main zones can be determined: the Unconfident zone (from 1–3), the Dilemma zone (from 4–6) and the Confident zone (from 7–9).

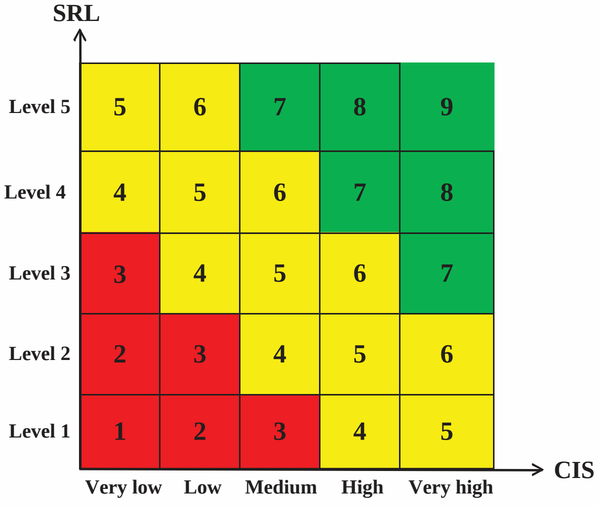
3.3 ***Delivery-process assessment***

3.3.1 *Activity and process feasibility levels*

The delivery process refers to all activities necessary for the production and implementation of the technical system once the offer has been accepted by the customer. It starts with an activity of design finalisation and ends with a manufacturing and packing activity. We make the assumption that the delivery process follows a typical waterfall model that is defined as a sequence of activities: design finalisation → manufacturing → packing, without any overlapping. From a factual performance point of view, when planning or designing a sequence of activities, attention should be given to three crucial aspects: (i) the skills of the resources that perform the activity (the designer for a design activity, for example), (ii) the availability of the resources which perform the activity (specific CAD system, raw materials, human resources) and (iii) the risk associated to the activity.

Therefore, in order to be able to define the feasibility of any activity of the delivery process, we propose a new factual metric, named Activity Feasibility Level (AFL). The knowledge of each activity's AFL leads us to determine the Process Feasibility Level (PFL). The feasibility indicates the ability of a specific activity or delivery process to be performed technically and economically (Vareilles et al. 2014). The AFL metric is based on three sub-metrics:

(i) Resource Skills Level (RSL): skills represent the operational ability to use knowledge (Wang and Wang 1998). A specific skill is used to perform an activity (e.g. designing a crane). As in Grabot and Letouzey (2000), an RSL is considered here as a grade in a given skill. The RSL scale is on five levels (1 is the lowest value, meaning 'poor' and 5 the highest one, meaning 'excellent') (see Table 4(a)). It is inspired by the Conversational Skills



	Very low	Low	Medium	High	Very high
Level 5	5	6	7	8	9
Level 4	4	5	6	7	8
Level 3	3	4	5	6	7
Level 2	2	3	4	5	6
Level 1	1	2	3	4	5

Figure 6. Overall Confidence In System determination.

Table 4. (a) Resource skills level (RSL), (b) Resource availability level (RAL), (c) Activity risk level (ARL).

Levels	Description	Definition
(a)		
5	Excellent	The use of the knowledge in the execution of the activity results in exceptional, regular and controlled performances
4	Good	The use of the knowledge in the execution of the activity results in better than adequate outcome
3	Adequate	The use of the knowledge in the execution of the activity is adequate
2	Fair	The use of the knowledge in the execution of the activity is occasionally inadequate
1	Poor	The use of the knowledge in the execution of the activity is awkward, disruptive, or results in negative performances
(b)		
5	Very easy	Resources are always easy to find
4	Easy	Resources are most of the time easy to find
3	Moderate	Resources are occasionally difficult to find occasionally easy to find
2	Difficult	Resources are most of the time difficult to find
1	Very difficult	Resources are always difficult to find
(c)		
5	Very low	Most risks are acceptable and no critical risks
4	Low	Most risks are undesirable and no critical risks
3	Moderate	Most risks are undesirable and few critical risks
2	High	Most risks are undesirable and some critical risks
1	Very high	Most risks are in the critical area

Rating Scale developed by Spitzberg and Adams (2007). It allows a factual assessment of the skills of the resource.

(ii) Resource Availability Level (RAL): resource availability refers to the ability of the bidder to find the required resources to perform an activity. These resources include human resources, machinery, software and raw materials. The proposed resource availability level is a five-level scale (see Table 4(b)). It allows a factual assessment of the ability of the bidder to find resources relevant to the achievement of an activity.

(iii) Activity Risk Level (ARL): A risk is associated with an uncertain event or condition that, if it occurs, has an effect on at least one project objective (delivery time, cost or quality) (Project Management Institute Inc 2008). In this work, we only consider the adverse effect of risk. The proposed ARL provides the risk level of each activity in the delivery process. The ARL scale is a five-level scale (the value 1 corresponds to the most risky and the value 5, to the less risky) (see Table 4(c)). It is based on a qualitative risk analysis using the probability and risk matrix. This method assumes that for a given activity, a prioritisation of risks has been conducted using a probability and impact matrix. Thus, the ARL of the activity can be determined by a mapping of all risks as defined by the ARL scale of Table 4(c).

As an equal emphasis is given to RSL, RAL and ARL, the AFL metric is calculated as the average of the three of them. The values of AFL are then comprised in the range [1, 5] and its scale is presented in Table 5(a) below.

After determining the AFL of each activity *i*, notated AFLi, a function is used to compute the Process Feasibility Level (PFL) as an aggregation of the different AFLi. It is important to recall that the phenomenon of integration described for technical systems (Section 3.2.1) is irrelevant for activities and therefore, does not exist in the delivery process. Although several aggregation mechanisms could be used to determine the PFL, we propose using a weighted average to calculate it. The PFL scale is shown in Table 5(a).

3.3.2 *Confidence in process metric (CIP)*

In the previous section, we defined the RSL, RAL, ARL, AFL and PFL metrics as a factual assessment of the feasibility of a delivery process. These metrics are strongly based on the availability of knowledge related to each activity. When this knowledge level is low, this does not strictly imply that the delivery process cannot be correctly achieved. Maybe the bidder does not have enough knowledge about resource skills, availability or risk, but he/she may have noticed in the past that some delivery processes worked better than others with regard to the performance, cost and delivery time. As for the technical system, this judgement or subjective feeling, based mainly on personal experience, should also be

Table 5. (a) Process feasibility level (PFL), (b) Five levels of the CIP of the process.

Values	Description
(a)	
4.46–5	Level 5
4–4.45	Level 4
2.5–3.99	Level 3
1.5–2.49	Level 2
1.0–1.49	Level 1
(b)	
4.46–5	Very high
4–4.45	High
2.5–3.99	Medium
1.5–2.49	Low
1.0–1.49	Very low

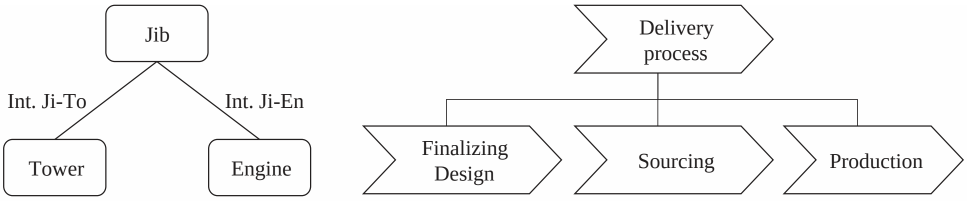


Figure 7. The Crane system and its delivery process.

considered. Therefore, for the delivery process, we suggest using the metric already proposed for the system in Section 3.2.2.

Therefore, given an activity i with a defined feasibility level AFL_i, we add a second metric, called Confidence In Process activity (CIP_i). As for the sub-system, the proposed CIP_i relies on the bidder's feeling and is based on the same three dimensions: (i) the experience of the bidder with regard to the considered activity, (ii) the similarity between the considered activity and previously performed activities and (iii) the feeling of the bidder on the considered activity. We propose assessing the CIP_i metric with the five-level scale shown in Table 3(a), taking into account simultaneously the three dimensions.

As for the PFL metric, we propose using a weighted average to compute the Confidence In Process (CIP) of the delivery process. Table 5(b) shows the scale of the CIP of the delivery process.

3.3.3 *Overall confidence in process (OCP)*

The overall confidence in process (OCP) aggregates the PFL and CIP metrics exactly like the system SRL and CIS metrics. The method presented in Section 3.2.3 is reused in exactly the same way.

4. Illustrative application of the proposed method

The aim of the proposed framework, gathering the previously outlined modelling elements and confidence metrics, is to support and assist the bidders in defining offers in both routine and non-routine design situations. Hereafter, we demonstrate and discuss the benefits of the proposal. After the overall description of the problem, three running scenarios are presented and discussed.

4.1 *Crane offer model for offer definition and evaluation*

The considered Crane system is composed of three sub-systems: one Jib, one Tower and one Engine. The architecture of the crane is presented by the non-oriented graph (left part of Figure 7), where the vertices of the graph represent the sub-systems and the edges represent the integrations between sub-systems. Only two integrations are considered, namely: (Jib and Tower) and (Jib and Engine).

The jib is characterised by its length (from 4–12 metres) and stiffness (low or high) and there are four potentials components (Ji_So_1, Ji_So_2, Ji_So_3 and Ji_So_4) with different combinations of length and stiffness. The tower is characterised by its height (from 5–15 metres) and stiffness (low or high) and there are four potential components (To_So_1, To_So_2, To_So_3 and To_So_4). Finally, the engine is characterised by its power (from 300 or 400 kW) and there are two potential components (En_So_1 and En_So_2). In this example, a length of a jib different from 4 and 8, and a height of a tower different from 5 and 10 are considered as new values and thus, refer to a new sub-system. Therefore, any sub-system corresponding to these values is a new sub-system. The delivery process gathers three activities (see right part of Figure 7): Finalising design (noted F_Design) with two possible resources (expert_designer or regular_designer), Sourcing with two possible resources (expert_buyer or regular_buyer) and Production with possible resources (expert_producer or regular_producer).

Each sub-system$_i$ is characterised by: a cost, a readiness TRL$_i$ (scale 1–9) and a confidence index CIS$_i$ (scale 1–5). The whole system is characterised by: a cost, a readiness SRL (scale 0–1) and its associated description (Level 1–5), as presented in Section 3.2.1, a confidence CIS (scale 0–1) and its associated description (Very Low to Very High), as presented in Section 3.2.2. It is also characterised by an overall confidence OCS (scale 1–9) and its associated zone (Unconfident, Dilemma, Confident) as presented in Section 3.2.3.

Each process activity$_i$ is characterised by: a duration, a cost, an activity feasibility AFL$_i$ (scale 1–5), a confidence CIP$_i$ (scale 1–5). The detailed RSL, RAL and ARL metrics are not shown for simplicity. Each process is characterised by: a duration, a cost, a feasibility PFL (scale 1–5) and its associated description (Level 1–5), as presented in Section 3.3.1, a confidence CIP (scale 1–5) and its associated description (Very Low to Very High), as presented in Section 3.3.2, an overall confidence OCP (scale 1–9) and its associated zone (Unconfident, Dilemma, Confident), as presented in Sections 3.2.3 and 3.3.3.

4.2 *Utilising the proposed method*

In this subsection, we present three scenarios with three different routine levels from very routine to less routine (including new values or new integrations). Each scenario is presented by two tables: one related to the system and one related to the process. Table 6 shows the status of each sub-system, system, activity and process at the beginning of the offer definition. The three scenarios can be operated at the url cofiade.mines-albi.fr (choose model 'IJPR 2016').

For each of the following scenario tables, each line is dedicated to an item (sub-system, system, activity and process) and shows (i) the use inputs or selection of an offer characteristic (in <u>**'bold underlined'**</u>) (ii) the consequences of these inputs on the other attributes (in 'regular format') once constraints have been propagated by a constrain-propagation aiding tool.

4.2.1 *Scenario 1: very routine offer*

This is the most routine scenario that corresponds to a pure configuration process, meaning that all sub-systems have been designed and all delivery activities have been already executed. Thus, overall confidence is very high and there is no finalising design activity.

In this scenario (Table 7), the bidder first selects a <u>**'4'**</u> metre jib with <u>**'low'**</u> stiffness that matches the sub-system Jib 'Ji_So_1'. According to the model and the TRL scale, as this sub-system already exists and is in operation, the tool deduces its cost '10' k€ and its TRL '9'. Then, as the user has full confidence in this technical solution, the maximum value for the confidence in this sub-system (CIS$_i$) is selected by the user as <u>**'5'**</u>. The height of the tower '5' is deduced by the tool (with respect to non-detailed technical constraints), then the user selects <u>**'low'**</u> stiffness, which matches the sub-system Tower 'To_So_1' and the tool deduces the engine power (technical constraints) and the correct sub-system Engine 'En_So_1'. For these two sub-systems, cost '30' and '8' k€ and TRL '9' are deduced by the tool according to the model and the TRL scale. The user then decides on a high level for confidence in the three sub-systems: <u>**'5'**</u>. Then, thanks to the model and aggregation mechanisms, the tool generates the technical system and computes its cost at '48' k€ and its confidence indicators: System Readiness Level SRL '1', Confidence In System CIS '1' and Overall Confidence In System OCS '9', as expected.

The scenario is similar for the delivery process (lower part of Table 7). Resource activities are selected by the user. According to this model and the AFL scale, as this process has already been defined and executed, the propagation tool deduces: the duration, the cost and the feasibility of each activity, while the user sets the confidences in the activities (CIP$_i$) (see Table 7). Then, the model and aggregation mechanisms allow the tool to compute the process cost, '112' k€,

Table 6. Initial status of sub-system, system, activity and process.

Technical system

				Readiness	Confidence	Overall confidence (OCS)
Sub-systems solutions	Attribute 1	Attribute 2	Cost (K€)	TRLi	CISi	
Jib Ji_So_1, Ji_So_2, Ji_So_3, Ji_So_4, Ji_So_New	[4, 12]	Low, Strong	[1, 80]	[1, 9]	[1, 5]	
Tower To_So_1, To_So_2, To_So_3, To_So_4, To_So_New	[5, 15]	Low, Strong	[1, 120]	[1, 9]	[1, 5]	
Engine En_So_1, En_So_2	[300, 400]		[8, 15]	[1, 9]	[1, 5]	

		Readiness		Confidence		Overall confidence (OCS)	
System solution	Cost (K€)	SRL	SRL description	CIS	CIS description	OCS level	OCS zone
Crane Cr_So_1, Cr_So_2, Cr_So_3, Cr_So_4, Cr_So_5, Cr_So_6, Cr_So_New	[10, 215]	[0, 1]	Level 1, Level 2, Level 3, Level 4, Level 5	[0, 1]	Very high, High, Medium, Low, Very Low	[1, 9]	Unconfident, Dilemma, Confident

Delivery Process

				Feasibility	Confidence	Overall confidence (OCP)
Activity	Resource	Duration (weeks)	Cost (K€)	AFLi	CIPi	
Sourcing	Expert_buyer, Regular_buyer	[1, 36]	[1, 300]	[1, 5]	[1, 5]	
Production	Expert_producer, Regular_producer	[1, 48]	[1, 400]	[1, 5]	[1, 5]	

			Feasibility		Confidence		Overall confidence (OCP)	
	Duration (weeks)	Cost (K€)	PFL	PFL description	CIP	CIP description	OCP level	OCP zone
Process	[12, 150]	[2, 1500]	[1, 5]	Level 1, Level 2, Level 3, Level 4, Level 5	[1, 5]	Very high, High, Medium, Low, Very Low	[1, 9]	Unconfident, Dilemma, Confident

Table 7. First scenario: very routine offer.

Technical System

				Readiness	Confidence	Overall confidence (OCS)
Sub-systems solutions	Attribute 1	Attribute 2	Cost (K€)	TRLi	CISi	
Jib Ji_So_1	**4**	**Low**	10	9	**5**	
Tower To_So_1	5	**Low**	30	9	**5**	
Engine En_So_1	300		8	9	**5**	

		Readiness		Confidence		Overall confidence (OCS)	
System solution	Cost (K€)	SRL	SRL description	CIS	CIS description	OCS level	OCS zone
Crane Cr_So_1	48	1	Level 5	1	Very High	9	Confident

Delivery Process

				Feasibility	Confidence	Overall confidence (OCP)
Activity	Resource	Duration (weeks)	Cost (K€)	AFLi	CIPi	
Sourcing	**Expert_buyer**	2	40	4.6	**5**	
Production	**Regular_producer**	8	72	4.3	**5**	

			Feasibility		Confidence		Overall confidence (OCP)	
	Duration (weeks)	Cost (K€)	PFL	PFL description	CIP	CIP description	OCP level	OCP zone
Process	10	112	4.45	Level 5	5	Very High	9	Confident

duration ‘10’ weeks and its confidence indicators that, as expected, are also shown to be very good: Process Feasibility Level PFL ‘4.66’, Confidence In Process CIP ‘5’ and Overall Confidence In Process OCP ‘9’.

This first scenario shows the basic support that the proposed model and confidence metric implemented in a relevant decision-support tool can provide to bidders for defining offers and estimating them in routine situations. It enables the bidder to rapidly and effectively define and estimate the technical systems and the delivery processes and to quantify confidence in the offer items.

4.2.2 *Scenario 2: less routine offer with new integration of sub-systems*

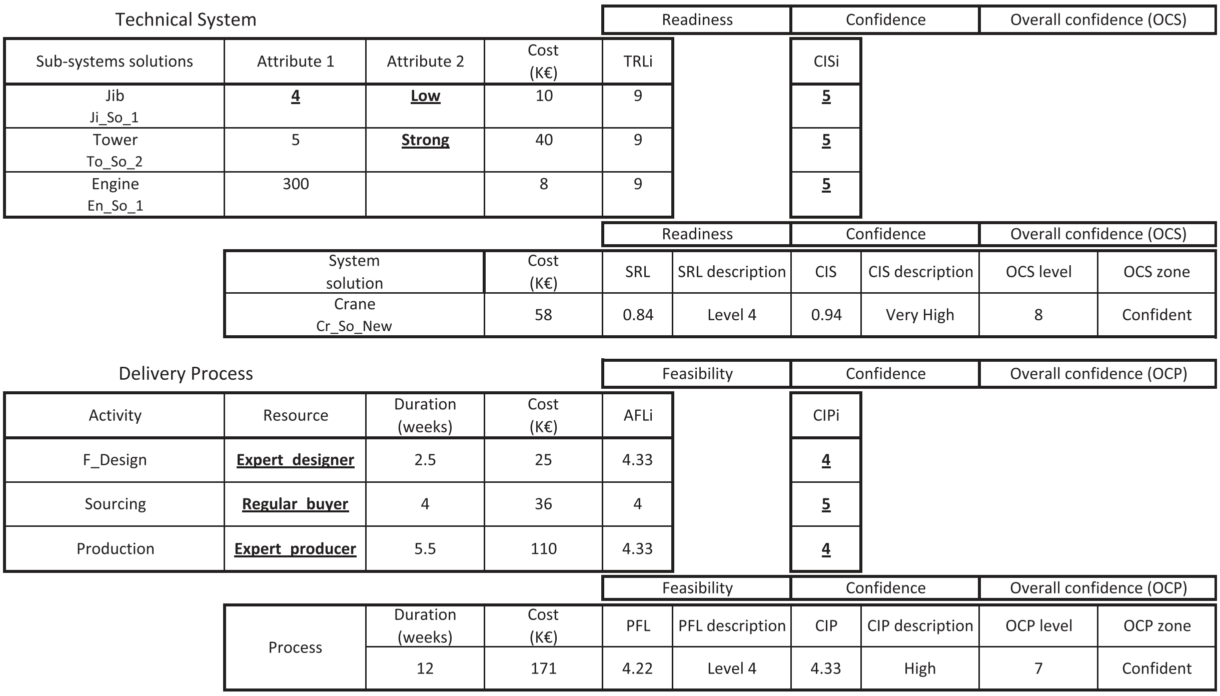
In this second scenario, two already designed and produced sub-systems that have never been integrated together in a system must be now integrated to propose a solution to a customer’s request. This illustrates the example of Figure 3 of Section 2.2.1 and the results are shown in Table 8.

On the system side, the bidder first selects exactly the same jib as for scenario 1: a **‘4’** metre jib with **‘low’** stiffness that matches the sub-system Jib ‘Ji_So_1’. But he/she then selects an already existing strong tower with **‘strong’** stiffness and according to the model and the TRL scale, the tool deduces the sub-system Tower ‘To_So_2’, with a cost of ‘40’ k€ and a TRL of ‘9’. The maximum Confidence In Sub-system CIS_i value **‘5’** is selected by the user as he/she is fully confident in this sub-system solution. The sub-system Engine of the previous scenario 1 is selected ‘En_So_1’.

The difference between these two scenarios comes from integration issues. Each sub-system has a maximum readiness level TRL_i = ‘9’ and confidence CIP_i = **‘5’** but at the system level, the readiness and confidence are not at their maximum values (see Table 8). Indeed, the integration of Ji_So_1 and To_So_2 has never before been achieved and therefore, the integration IRL_{ij} is not so high. The user also does not select the highest CIS_{ij} for this integration as he/she is not fully confident. Thus, thanks to the model and the aggregation mechanisms the tool computes: SRL = ‘0.84’, CIS = ‘0.94’ and the Overall Confidence in System (OCS) = 8. These confidence values are lower than those in the first scenario (both at ‘1’).

From the process point of view (lower part of Table 8), a new F_Design activity is necessary for previous integration engineering. Compared to the first scenario, the AFL_i and CIP_i of the activities have decreased (see Table 8). Thus, thanks to the model with the aggregation mechanism, at the process level, the tool logically provides lower values for the Process Feasibility Level PFL = ‘4.22’, the Confidence In Process CIP = ‘4.33’ and the Overall Confidence in Process OCP = ‘7’.

Table 8. Second scenario: offer with a new integration of two sub-systems.



Technical System

Sub-systems solutions	Attribute 1	Attribute 2	Cost (K€)	Readiness TRLi	Confidence CISi	Overall confidence (OCS)
Jib Ji_So_1	**4**	**Low**	10	9	**5**	
Tower To_So_2	5	**Strong**	40	9	**5**	
Engine En_So_1	300		8	9	**5**	

		Readiness		Confidence		Overall confidence (OCS)	
System solution	Cost (K€)	SRL	SRL description	CIS	CIS description	OCS level	OCS zone
Crane Cr_So_New	58	0.84	Level 4	0.94	Very High	8	Confident

Delivery Process

Activity	Resource	Duration (weeks)	Cost (K€)	Feasibility AFLi	Confidence CIPi	Overall confidence (OCP)
F_Design	**Expert_designer**	2.5	25	4.33	**4**	
Sourcing	**Regular_buyer**	4	36	4	**5**	
Production	**Expert_producer**	5.5	110	4.33	**4**	

			Feasibility		Confidence		Overall confidence (OCP)	
	Duration (weeks)	Cost (K€)	PFL	PFL description	CIP	CIP description	OCP level	OCP zone
Process	12	171	4.22	Level 4	4.33	High	7	Confident

This second scenario illustrates the help that the bidders can be given in less routine situations. Even if the selected sub-systems have high TRL, the decision-support tool is able to take into account the fact that they have never been integrated together and provides to the bidder with the confidences levels of the whole technical system and delivery process. Once designed, produced and delivered, the knowledge relevant to this new integration has to be capitalised and the knowledge model updated.

4.2.3 *Scenario 3: much less routine offer with new sub-systems*

In this last scenario (Table 9), two new sub-systems are now considered. We assume an interpolation for the jib length, while we consider an extrapolation for the tower height. This means that we consider that, up to now, only two lengths exist for the jib: 4 and 8 m (the range [4, 12] indicates allowed out-of-range possibilities, see Figure 2) and two heights exist for the tower: 5 and 10 m (the range [5, 15] indicates out-of-range possibilities). For this particular much less routine offer, a new jib of 6 metres and a new tower of 15 m must be engineered, produced and integrated.

On the system side, the bidder first selects the jib length equal to **'6'** metres. This length does not correspond to any existing sub-system and the tool proposes a new jib 'Ji_So_New' with a 'strong' stiffness. A similar behaviour for a **'15'** metre tower can be seen. For these two new sub-systems, the tool cannot modify the cost range (there is no knowledge about the cost of the new sub-systems) but reduces the possible range of the readiness to '5'. Finally the user estimates and chooses, for the jib and the tower, a cost (respectively, **'40'** k€ and **'118'** k€ and a confidence level CIS_i (**'5'** and **'2'**) (see Table 9). The high CIS_i for the jib and the low one for the tower come from the interpolation design for the jib and the extrapolation design for the tower. An existing high-power engine is selected 'En_So_2'. At the system level, readiness level is lower, SRL = '0.48' and confidence too, CIS = '0.65'. The Overall Confidence in the System OCS drops down to '4' and tends towards a dilemma situation.

On the process side (Table 9), the main differences concern the duration and cost of the engineering activity (F_Design), which comes from the fact that two main sub-systems must be engineered and integrated. For this same activity, the Activity Feasibility Level ($AFL_i = 3.66$) deduced by the tool and the Confidence In Process activity CIP_i = **'3'** defined by the bidder are also lower. The two other activities see their duration and cost increasing normally according to the system size and its complexity. At the process level, thanks to the model with the aggregation

Table 9. Third scenario: offer with two new sub-systems.

Technical System

				Readiness	Confidence	Overall confidence (OCS)
Sub-systems solutions	Attribute 1	Attribute 2	Cost (K€)	TRLi	CISi	
Jib Ji_So_New	6	Strong	40	5	5	
Tower To_So_New	15	Strong	118	5	2	
Engine En_So_2	400		15	9	5	

		Readiness		Confidence		Overall confidence (OCS)	
System solution	Cost (K€)	SRL	SRL description	CIS	CIS description	OCS level	OCS zone
Crane Cr_So_New	173	0.48	Level 2	0.65	Medium	4	Dilemma

Delivery Process

				Feasibility	Confidence	Overall confidence (OCP)
Activity	Resource	Duration (weeks)	Cost (K€)	AFLi	CIPi	
F_Design	**Expert_designer**	11	110	3.66	3	
Sourcing	**Regular_buyer**	10	80	4	4	
Production	**Expert_producer**	15	300	3	4	

			Feasibility		Confidence		Overall confidence (OCP)	
	Duration (weeks)	Cost (K€)	PFL	PFL description	CIP	CIP description	OCP level	OCP zone
Process	36	490	3.55	Level 3	3.66	Medium	5	Dilemma

mechanisms, the tool provides lower values for the feasibility, PFL = '3.55', the confidence, CIP = '3.66' and the overall confidence in the process, OCP = '5', which also leads to a dilemma situation.

This third scenario shows that our proposals, bringing together the proposed model, the confidence indicators and the aggregation mechanisms implemented in a relevant tool, can provide the bidder with the same supports as in the previous simpler scenarios, but in a much less routine situation. Even if new sub-systems have to be engineered, produced and integrated, the decision-support tool is able to take into account these new kinds of sub-systems and activities if, and only if, they have been identified and characterised beforehand by the system-design and the delivery-process departments of the bidder. Once designed, produced and delivered, this new system knowledge has to be capitalised and the model updated for both system and process sides.

5. Conclusion and further research

The goal of this article is to define a new framework that supports bidders during the definition of their offers in non-routine situations. An offer is composed of a technical system and its delivery process. The originality of this work lies in the fact that we consider situations where the offer proposed to the customer is not supported by a detailed engineering or design activity; only the main key decisions are made. This allows: (i) a lower workload for bidders, (ii) more customers and a stronger presence in the relevant market and, (iii) in the case of a rejected offer, less wasted energy. The proposed framework is based on an extended configuration model and an original confidence metric. As far as we know, in the openly available scientific literature there are no significant works dealing simultaneously with our problem keywords: bidding process without detailed design, design knowledge, system and process design, risk and confidence.

Firstly, we have shown that the level of routine of the offer is a key aspect and therefore, suggested using the configuration approach (considered as an ultimate routine situation) as a basis. We then proposed constraint-based modelling elements that allow the configuration techniques to be extended towards less routine situations. System and process models have been updated with the possibility of choosing/deciding (i) new values (out of range of existing system/process) that can cope with new system/process descriptions (ii) new integration of already existing sub-systems and (iii) new engineering activities necessary as soon as any new item is included in the offer. It must be noted that, while many scientific papers can be found on the subject of modelling configuration problems, none of them consider 'out-of-range' configuration.

Secondly, as the offer can no longer be analysed in detail (system technologies, macro-activities and key resources are simply identified), the bidders take a risk on their ability to produce a technical system that fulfils all customer expectations (performance, cost and delivery time) once the offer is accepted. Thus, four original metrics for the explicit characterisation of confidence in an offer in a non-routine design context have been proposed. These metrics quantify separately the technical system (SRL and CIS) and its delivery process (PFL and CIP), and also dissociate factual aspects (SRL and PFL) from human-based ones (CIS and CIP). Each metric is valuated at the lower level (sub-system/activity) and aggregated at the upper level (system/process). With regard to factual metrics, the readiness notion (SRL and TRL) is used for the technical system and a feasibility notion (PFL and AFL) is proposed for the delivery process. Regarding human-based metrics, for both system and process a similar confidence notion (CIS, CISi, CIP, CIPi) is proposed, relying on bidder experience and feelings as well as similarity between offers. Finally, the overall confidence metric at the top level (OCS and OCP) aggregates both factual and subjective confidence and helps bidders to make the right decision by choosing the most attractive offer to submit, knowing the risk involved. To the best of the authors' knowledge, there are currently no works dealing with issues related to offer confidence metrics covering system/process characterisation, or factual/human aspects on two abstraction levels.

Using a constraint-based configuration tool, we have integrated the proposed model extensions and associated confidence metrics. We then described a use case dealing with the definition of a crane offer (which can be operated at the url cofiade.mines-albi.fr, model 'IJPR 2016'). In order to illustrate our proposals, we have presented three offer scenarios with different degrees of routine and the assessment of the proposed confidence indicators. The scenarios reveal that when offer definition requires performing engineering activities (in non-routine situations), the confidence metrics can significantly decrease and can warn the bidder about a potentially risky situation. Above all, when the person in charge of an offer definition does not have a great deal of experience, the proposed metrics and associated tool can help avoid making an offer that will not be achievable if the customer accepts it. Generally, given the increasing number of offers that need to be defined, the lack of experienced bidders (due to staff turnover), the requirement to reduce bidding workload and the difficulty of producing detailed design for every offer, bidders are taking more and more risks and thus, require computerised assistance. The proposals in this article and our future works clearly aim to address this situation.

Two kinds of future research can be investigated. In the short-term, one area consists in confronting our proposals with small- and medium-sized industrialists in the secondary and tertiary sectors. This work will be carried out during a new four-year collaborative project which aims to develop ‘Software tools and processes for bid elaboration’. This project is based firstly on the maturity of the technical system, and confidence in the offer and secondly, on the risks taken during its delivery process. Up-to-now, after presenting and discussing our proposals and first-use cases, we have mainly received positive feedback. We now need to verify the usability and scaling-up of our proposals in an industrial context. The long-term work should consider the development of a multi-criteria decision-making method that allows consideration of the uncertainty related to the offer characteristics (cost, delivery date, etc.) and guides decision-makers in their choices in a multi-criteria framework. For this purpose the proposed confidence metrics may be used to represent the uncertainty related to offer characteristics (Dubois and Prade 2012). In this context, one could consider using possibility theory or another similar approach in order to take into account the uncertainties in the decision-making process. This will enable the bidder to choose the most relevant offer not only based on standard indicators (cost, delivery duration) but also considering confidence indicators as a way to take into account uncertainties in these standard indicators.

Acknowledgement

The authors would like to thank all ANR OPERA partners for their implications in our research work.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Aldanondo, Michel, and Elise Vareilles. 2008. “Configuration for Mass Customization: How to Extend Product Configuration towards Requirements and Process Configuration.” *Journal of Intelligent Manufacturing* 19 (5): 521–535. doi:10.1007/s10845-008-0135-z.

Barták, Roman, Miguel A. Salido, and Francesca Rossi. 2010. “Constraint Satisfaction Techniques in Planning and Scheduling.” *Journal of Intelligent Manufacturing* 21: 5–15. doi:10.1007/s10845-008-0203-4.

Brown, D. C., and B. Chandrasekaran. 1985. “Expert Systems for a Class of Mechanical Design Activity.” *Knowledge Engineering in Computer-Aided Design*: 259–282.

DECIDE. 1998. “DECIDE.” http://cordis.europa.eu/project/rcn/33616_fr.html.

Dikmen, Irem, M. Talat Birgonul, and A. Kemal Gur. 2007. “A Case-Based Decision Support Tool for Bid Mark-up Estimation of International Construction Projects.” *Automation in Construction* 17 (1): 30–44. doi:10.1016/j.autcon.2007.02.009.

Dubois, Didier, and Henri Prade. 2012. *Possibility Theory: An Approach to Computerized Processing of Uncertainty.* New York: Springer Science & Business Media.

Felfernig, Alexander, Gerhard Friedrich, Dietmar Jannach, Markus Stumptner, and Markus Zanker. 2003. “Configuration Knowledge Representations for Semantic Web Applications.” *Ai Edam* 17 (1): 31–50. doi:10.1017/S0890060403171041.

Felfernig, Alexander, Lothar Hotz, Claire Baglay, and Juha Tiihonen. 2014. *Knowledge-Based Configuration from Research to Business Cases*. Amsterdam: Morgan Kaufmann.

Grabot, Bernard, and Agnès Letouzey. 2000. “Short-term Manpower Management in Manufacturing Systems: New Requirements and DSS Prototyping.” *Computers in Industry* 43 (1): 11–29. doi:10.1016/S0166-3615(00)00058-0.

Henderson, Rebecca M., and Kim B. Clark. 1990. “Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms.” *Administrative Science Quarterly* 35 (1): 9–30.

Huang, G. Q., and K. L. Mak. 2000. “WeBid: A Web-Based Framework to Support Early Supplier Involvement in New Product Development.” *Robotics and Computer-Integrated Manufacturing* 16 (2–3): 169–179. doi:10.1016/S0736-5845(00)00005-3.

Knaggs, Michael, John Ramsey, Alfred Unione, Dennis Harkreader, John Oelfke, Dale Keairns, and William Bender. 2015. “Application of Systems Readiness Level Methods in Advanced Fossil Energy Applications.” *Procedia Computer Science* 44: 497–506. doi:10.1016/j.procs.2015.03.071.

Kroemker, Mathias, Klaus-Dieter Thoben, Andreas Kebbel, and Hans Juergen Schoenert. 1997. “Integrated System for Simultaneous Bid Preparation.” *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics* 4: 3597–3602. https://www.scopus.com/inward/record.url?eid=2-s2.0-0031371620&partnerID=40&md5=e4690e2905dff43f2424c49aa27f4c7d.

Kromker, Mathias. 1998. “BIDPREP-towards Simultaneous Bid Preparation.” *International Journal of Computer Integrated Manufacturing* 11 (1): 45–51. doi:10.1080/095119298130967.

Leopoulos, Vrassidas N., and Konstantinos A. Kirytopoulos. 2004. “Risk Management: A Competitive Advantage in the Purchasing Function.” *Production Planning & Control* 15 (7): 678–687. doi:10.1080/09537280412331298238.

Lin, Ching Torng, and Ying T. Chen. 2004. “Bid/No-Bid Decision-making – A Fuzzy Linguistic Approach.” *International Journal of Project Management* 22 (7): 585–593. doi:10.1016/j.ijproman.2004.01.005

London, Mark A., Thomas H. Holzer, Timothy J. Eveleigh, and Shahryar Sarkani. 2014. “Incidence Matrix Approach for Calculating Readiness Levels.” *Journal of Systems Science and Systems Engineering* 23 (4): 377–403. doi:10.1007/s11518-014-5255-8.

Magnaye, Romulo B., Brian J. Sauser, and Jose E. Ramirez-Marquez. 2010. “System Development Planning Using Readiness Levels in a Cot of Development Minimization Model.” *Systems Engineering* 13 (4): 311–323. doi:10.1002/sys.

Magnaye, Romulo, Brian Sauser, Peerasit Patanakul, David Nowicki, and Wesley Randall. 2014. “Earned Readiness Management for Scheduling, Monitoring and Evaluating the Development of Complex Product Systems.” *International Journal of Project Management* 32 (7): 1246–1259. doi:10.1016/j.ijproman.2014.01.009.

Mankins, John C. 1995. “Advanced Concepts Office Office of Space Access and Technology.” *White Paper* 1: 4–8. doi:10.1017/CBO9781107415324.004.

Mankins, John C. 2009. “Technology Readiness and Risk Assessments: A New Approach.” *Acta Astronautica* 65 (9–10): 1208–1215. doi:10.1016/j.actaastro.2009.03.059.

McConkie, Eileen, Thomas A. Mazzuchi, Sharam Sarkani, and D. Marchette. 2013. “Mathematical Properties of System Readiness Levels.” *Systems Engineering* 16 (4): 391–400. doi:10.1002/sys.

Mida, F. H., and F. Vernadat. 2009. “A Constraint Approach (Flexible CSP) for Alternative Cost Estimation of a Mechanical Product.” *International Journal of Production Research* 47 (2): 305–320. doi:10.1080/00207540802425872.

Mittal, Sanjay, and Felix Frayman. 1989. “Towards a Generic Model of Configuration Tasks.” *Proceedings of the Eleventh International Joint Conference on Artificial Intelligence* 2: 1395–1401. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.80.3469&rep=rep1&type=pdf%5Cnhttps://ijcai.org/PastProceedings/IJCAI-89-VOL-2/PDF/087.pdf.

Pitiot, Paul, Michel Aldanondo, Elise Vareilles, Paul Gaborit, Meriem Djefel, and Sabine Carbonnel. 2012. “Concurrent Product Configuration and Process Planning, towards an Approach Combining Interactivity and Optimality.” *International Journal of Production Research* 7543: 1–18. doi:10.1080/00207543.2011.653449.

Pitiot, Paul, Michel Aldanondo, and Elise Vareilles. 2014. “Concurrent Product Configuration and Process Planning: Some Optimization Experimental Results.” *Computers in Industry* 65 (4): 610–621. doi:10.1016/j.compind.2014.01.012.

PRiMA. 2002. http://www.esi2.us.es/prima/Partners1.html.

Project Management Institute Inc. 2008. *A Guide to the Project Management Body of Knowledge*. Pennsylvania: Project Management Institute.

Romero Bejarano, Juan Camilo, Thierry Coudert, Elise Vareilles, Laurent Geneste, Michel Aldanondo, and Joël Abeille. 2014. “Case-Based Reasoning and System Design: An Integrated Approach Based on Ontology and Preference Modeling.” *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 28 (1): 49–69. doi:10.1017/S0890060413000498.

Sabin, D., and R. Weigel. 1998. “Product Configuration Frameworks-a Survey.” *IEEE Intelligent Systems* 13 (4): 42–49.

Sadin, Stanley R., Frederick P. Povinelli, and Robert Rosen. 1989. “The NASA Technology Push towards Future Space Mission Systems.” *Acta Astronautica* 20 (9–10): 73–77.

Sauser, Brian, Jose E. Ramirez-Marquez, Romulo Magnaye, and Tan Weiping. 2008. “A Systems Approach to Expanding the Technology Readiness Level within Defense Acquisition.” https://www.dtic.mil/dtic/tr/fulltext/u2/a530242.pdf.

Shokri-Ghasabeh, Morteza, and Nicholas Chileshe. 2016. “Critical Factors Influencing the Bid/No Bid Decision in the Australian Construction Industry.” *Construction Innovation* 16 (2): 127–157. doi:10.1108/CI-04-2015-0021.

Soininen, Timo, Juha Tiihonen, Tomi Männistö, and Reijo Sulonen. 1998. “Towards a General Ontology of Configuration.” *Ai Edam* 12 (4): 357–372. doi:10.1017/S0890060498124083.

Spitzberg, Brian H., and Thomas W. Adams. 2007. “CSRS the Conversational Skills Rating Scale.” https://www.natcom.org/uploadedFiles/Teaching_and_Learning/Assessment_Resources/PDF-Conversation_Skills_Rating_Scale_2ndEd.pdf.

Suh, N. P. 1990. *The Principles of Design (Oxford Series on Advanced Manufacturing)*. New York: Oxford University Press.

Sylla, A., E. Vareilles, M. Aldanondo, T. Coudert, and L. Geneste. 2017. “Customer/Supplier Relationship: Reducing Uncertainties in Commercial Offers thanks to Readiness, Risk and Confidence Considerations.” In *Advances on Mechanics, Design Engineering and Manufacturing*, edited by B. Eynard, V. Nigrelli, S. Oliveri, G. Peris-Fajarnes, and S. Rizzuti, 1115–1122. Catane: Springer.

Tan, Weiping, Brian J. Sauser, and Jose Emmanuel Ramirez-Marquez. 2011. “Analyzing Component Importance in Multifunction Multicapability Systems Developmental Maturity Assessment.” *IEEE Transactions on Engineering Management* 58 (2): 275–294. doi:10.1109/TEM.2010.2071877.

Ulrich, Karl T., and Steven D. Epinger. 2016. *Product Design and Development*. 6th ed. New York: McGraw-Hil.

Vanwelkenhuysen, Johan. 1998. “The Tender Support System.” *Knowledge-based Systems* 11 (5–6): 363–372. doi:10.1016/S0950-7051(98)00065-3.

Vareilles, Élise, Michel Aldanondo, Aurélien Codet de Boisse, Thierry Coudert, Paul Gaborit, and Laurent Geneste. 2012. “How to Take into Account General and Contextual Knowledge for Interactive Aiding Design: Towards the Coupling of CSP and CBR Approaches.” *Engineering Applications of Artificial Intelligence* 25 (1): 31–47. doi:10.1016/j.engappai.2011.09.002.

Vareilles, Elise, Thierry Coudert, Michel Aldanondo, Laurent Geneste, and Joel Abeille. 2014. “System Design and Project Planning: Model and Rules to Manage Their Interactions.” *Integrated Computer-Aided Engineering* 1: 1–5.

Wang, H.-F., and C. H. Wang. 1998. “Modelling of Optimal Expansion of a Fuzzy Competence Set.” *International Transactions in Operational Research* 5 (5): 413–424. doi:10.1111/j.1475-3995.1998.tb00124.x.

Zhang, Linda L., Elise Vareilles, and Michel Aldanondo. 2013. “Generic Bill of Functions, Materials, and Operations for SAP 2 Configuration.” *International Journal of Production Research* 51 (2): 465–478. doi:10.1080/00207543.2011.652745