An ontology-based knowledge management prototype supporting decision-making in technology appraisal

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Abstract

Since decisions concerning technology appraisal are of strategic importance to organizations, issues involved are complex and the nature of the decision is difficult to be captured and reused for future decisions in the changing technology selection environment. The proposed knowledge management framework addresses the technology selection and appraisal problem through an ontology-based approach that captures and makes reusable the equipment purchasing process. This approach enhances and empowers existing knowledge reuse by allowing users to navigate into the underlying knowledge of the selection and appraisal application domain. Furthermore, a real case-study from the industry is presented to illustrate the proposed technique.

Keywords: Technology appraisal, Knowledge Management, Machinery acquisition, Ontology, Gap analysis

Paper type: Research paper

ACM Classification: H.5.2, I.2.0, J7
1. **Introduction**

Practical engineering and management requires choices among competing alternatives. The term “alternative” means a distinct option for a purchase or project decision (Hendrickson and McNeil, 1999). The present paper is focused on the selection of the best project from a set of mutually exclusive projects, i.e. when there are several competing projects or options and only one of them can be built or purchased. Thus, it is intended to provide a model for choosing the best among distinct alternatives in equipment purchasing.

The issues involved in technology selection are so complex, the needs and economies are so variable, and the trade-offs, which must be made, are so qualitative that it is not always meaningful to suggest a single, universal approach to selection. But no matter how difficult this is, it is very useful to provide a framework and a basis from which the user can confidently determine a selection approach, which is appropriate to specific circumstances.

On the other hand, world economy has been transformed into a knowledge economy. In that economy the application of knowledge is the main means of production and has become more important than traditional resources, such as labour, capita or base materials. Traditional economy that was primarily driven by transformational activities has been transformed into knowledge economy where the highest-value activities are complex interactions between people and systems. This shift from transformation activities to interactions represents a broad shift in the nature of economic activity. Economic success and most productivity gains in the future are going to be in interactions (Tome, 2008).

One of the key issues for the successful integration of knowledge flows into the enterprise activities is active user involvement. This is achieved through continuous interactions between experts (knowledge workers) and candidates. In essence, active user involvement can be considered as a knowledge-creation spiral that emerges when the interaction between tacit
and explicit knowledge is elevated dynamically from lower to higher ontological levels (Nonaka and Takeuchi, 1995). Technology selection and in particular equipment purchasing is not a one-off process. It takes place repeatedly within organizations. Representing equipment purchasing selection processes and in particular assessment methodologies as a business process model will enhance considerably individual and collective knowledge transfer and hence, long term business efficiency.

This paper addresses the knowledge transfer requirement of the technology selection problem through an ontology-based approach that captures and makes reusable the equipment purchasing process and assists in identifying (a) the specifications requested by the users’ organization, (b) those offered by various candidate vendors’ organizations and (c) in performing specifications gap analysis as a prerequisite for effective and efficient technology selection. Furthermore, a case study from the iron and steel industry in Greece is presented to illustrate the proposed technique. This case study describes a real application of this model and it is concerned with the selection of the best from a set of alternatives hydraulic scrap shears for the scrap yard of a Greek steel mill.

2. A Review of Equipment Purchasing Decision Models

The vast majority of the decision models apply to the final choice phase of the selection process. However, there are also methods for problem definition and formulation of criteria, as well as decision methods for pre-qualification of suitable suppliers (Ordoobadi, 2008). A good supplier selection process is very important for efficient manufacturing (Sevkli et al., 2008; Park et al., 2010). Some of the methods for pre-qualification, which could be used in the final choice as well, are the following (De Boer et al., 2001):

- **Categorical methods**: Basically, categorical methods are qualitative models. Based on historical data and the buyer’s experience, suppliers are evaluated on a set of criteria.
• **Data envelopment analysis (DEA):** DEA is built around the concept of the “efficiency” of a decision alternative. The alternatives are evaluated on benefit criteria (output) and cost criteria (input) (Easton et al., 2002).

• **Cluster analysis (CA):** CA uses a classification algorithm to group a number of items, which are described by a set of numerical attribute scores into a number of clusters. The result is a classification of suppliers in clusters of comparable suppliers.

• **Case-based-reasoning (CBR) systems:** Basically, a CBR-system is a software-driven database, which provides a decision-maker with useful information and experiences from similar, previous decision situations.

The decision models for the final choice-phase can be distinguished in three ways. Almost two-thirds of the existing supplier choice models can be characterized as “single-deal” or “package” models. These models consider the selection of a supplier for one product or a group of items at once. However, “multiple-deal” models take into account interdependencies that could exist among different products in or across the product groups as well as a supplier may perform on different levels within a product group. A third distinction concerns the specific technique used in modeling the choice phase. Decision models of this kind, which are usually based on several multi-criteria, mathematical programming, and other advanced methodologies (Talluri and Narasimhan, 2003), are mainly the following (De Boer et al., 2001):

• **Linear weighting models:** In linear weighting models weights are given to the criteria, the biggest weight indicating the highest importance. Ratings on the criteria are multiplied by their weights and summed in order to obtain a single figure for each supplier. The supplier with the highest overall rating can then be selected.

• **Total cost of ownership (TCO) models:** TCO-based models for supplier choice basically consists of summarization and quantification of all or several costs associated with the choice of vendors and
subsequently adjusting or penalizing the unit price quoted by the supplier with this figure in some way.

- **Mathematical programming (MP) models:** MP allows the decision-maker to formulate the decision problem in terms of a mathematical objective function that subsequently needs to be maximized (e.g. maximize profit) or minimized (e.g. minimize costs) by varying the values of the variables in the objective.

- **Statistical models:** Statistical models deal with the stochastic uncertainty related to the vendor choice. Although stochastic uncertainty is present in most types of purchasing situations, only very few supplier choice models really handle this problem.

Apart from the above-presented models, one should also mention some other decision methods that could be applied in more specific cases of purchasing. For instance, there are decision support frameworks and models applicable in international purchasing, e.g. models used to identify those items which can beneficially be procured from abroad and those which are best obtained locally (Smith, 1999), in purchasing of bulk raw materials, e.g. models used to select items and vendors, and to decide ordering quantities (Gao and Tang, 2003), in strategic purchasing, e.g. models used to define the number of suppliers needed in the presence of risks (Berger et al., 2004) or models used to support “make or buy decision” (Humphreys et al., 2000) etc. Nevertheless, these types of decision models are not appropriate for ordinary projects concerning technology selection and equipment purchasing. For these projects, in contrast, one could use most of the models presented previously in this section, which may prove to be useful throughout the selection process.

It must be noted, though, that, while the number of decision tools seems to grow steadily, there is little empirical scientific evidence of the practical merit of such tools in the supplier selection practice. Usually, the decision tools for supplier selection are only provisionally tested on a fictitious example for illustrative purposes although usually based on input data that
were gathered in practice. The few real empirical applications appear without a systematic and comprehensive analysis of such aspects as user-appreciation, costs of building the model, the availability of data, the integration in existing systems and procedures and so on (De Boer and Van der Wegen, 2003). Moreover, not all of these methods are equally useful in every possible purchasing situation. Even if the existing articles on methods for supplier selection do not sufficiently address this contextual issue (often they assume, explicitly or implicitly, that their method is applicable in all purchasing contexts), at most, a reference is made to a particular industry in which a method has been empirically tested or the need to change the criteria considered when applying the method to another type of product (De Boer et al., 2001).

3. **Design of an Ontology-based Technology Selection model**

All the materials (content) available for technology selection (books, articles, white papers, documents, flowcharts etc.) are essentially structured as collections of multimedia objects. However, this structuring of the material only provides for manipulating and restructuring multimedia objects, without making the underlying knowledge explicit and reusable. The proposed methodology aims to fill in this gap of knowledge externalization, diffusion and reusability.

The approach utilizes three repositories: (a) the *ontology repository* that contains all the relevant concepts (high level specifications, e.g. high level technology selection specifications) and the relations between them, (b) the *content repository* that contains all relevant supportive material (from the entire selection process, e.g. the RFP, the vendor offers, pictures, drawings, supportive material etc.) and (c) the *knowledge repository* that contains all the detailed case (equipment) specific knowledge as instances related to high level concepts from the *ontology repository* and enhanced with specific supportive multimedia from the *content repository* (specification
requirements and detailed specifications per equipment offered per vendor) (Macris, 2011).

Technology selection flows that are based on the proposed approach allow users to navigate into the domain of knowledge represented in the form of a process flow. Thus, the user involved in a technology selection process is guided to navigate into the specific process flow under consideration. To enhance his/her understanding of each ontology construct included in a process flow, the user can access relevant supportive material in the form of multimedia objects and identify the relation of the particular construct with other relevant constructs.

3.1. **Ontology-based gap analysis for technology selection**

Based on the ontology-based technology selection model outlined, specifications will be first categorized in a hierarchical manner in a bottom-up approach, from detailed to general specifications in order to define a general specifications’ model applicable to all technology selection processes. Then this model will be applied to each and every equipment purchasing specific process, in a top-down approach (from general to equipment specific), in order to (a) identify the specifications required, (b) identify the specifications offered per vendor and (c) perform a specifications’ gap analysis per vendor and rank vendors based on this analysis. In broad terms, such an approach consists of the following stages:

1. Identify the specifications required by various technology selection functions and organizational positions and define an organization-wide technology selection assessment model, based on these specifications, as a partially ordered set represented by a specifications’ hierarchy or a specifications’ network. The specifications’ structure is defined through a recursive application of generalization and aggregation relationships. Hence specifications are combined into more complex specifications. The result of this stage would be a definition of specifications as encapsulations of the specifications required to perform various technology selection functions.
2. Identify the specifications required by a specific technology selection process for equipment purchasing as documented in the RFP (request for proposal) and other internal documents and assign tightly matching specifications to each and every requirement posed to prospective vendors. Identify the required relationships and define their semantics. For example, the relationship “Appraises” is defined between Specifications (technical or commercial) and Importance (e.g. mandatory, desirable, optional, future). The “Appraises” relationship characterizes the importance of a specific specification during the evaluation process for a specific equipment purchasing process. The result of this stage would be a scheme for further evaluating vendor equipment proposals.

3. Identify the proposed vendor equipment specifications and perform a specifications’ gap analysis between the specifications required and the specifications for the equipment offered per vendor based on a closest match approach. The result of this stage would be a detailed specifications’ gap analysis per vendor.

4. Use the results of the specifications’ gap analysis in combination with a scoring methodology developed to aid in screening and selecting the best equipment from a set of possible alternatives, in order to rank the various vendors and select the proposed vendor.

This listing of stages is not intended to imply a once-through process as the control action necessary at any stage may involve significant iteration.

3.2. *The technology selection Ontology*

All selection mechanisms reflect somehow the selection of what creates most net value to the buyer. Therefore, selection reflects the criteria used by customers, shareholders and internal stakeholders (Janszen, 2000). Technology selection involves decision-makings that are critical to the profitability and growth of a company in the increasingly competitive global environment. However, these selection processes require the analysis of a large number of technical and economic (tangible) as well as analytical
(intangible) factors (specifications) in a decision support environment. Those specifications can be grouped into two major categories: (a) technical and (b) commercial. They can also be grouped according to their function (Input / Process / Output / Accessories) and their importance in the selection process (Mandatory / Desirable / Optional / Future). Specifications ‘refer to’ either the vendor or the equipment. Costs can also be grouped into various categories (Timmreck, 1973).

Figure 1

Figure 1 shows the classes’ (concepts) diagram of the technology selection ontology constructed using the SemTalk21 ontology editor for MS-Office 2003, a Visio 2003 add-in that provides all the modeling functionality needed to create ontologies complying with the standards set by W3C’s (the World Wide Web Consortium) recommendation OWL2.

4. The case study

The above model has been applied for the selection of a hydraulic scrap shear for the scrap yard of a major Greek steel mill equipped with electric arc furnace (EAF). The effectiveness of EAF steelworks depends greatly on the management and quality of the scrap (Bliss, 2000). During melting, large pieces of scrap may cause electrode breakage as they fall (International Iron and Steel Institute, 1987). Furthermore, low-density scrap requires more boxes to be handled in the scrap yard and at the furnace to attain the calculated metallic charge (Gantz, 1985). For that reason, steel mills purchase and install scrap shears in order to boost their productivity by increasing the scrap density.

1 http://www.semtalk.com
2 Web Ontology Language. OWL facilitates better machine interpretability of Web content than that supported by other languages like XML, RDF, and RDF Schema (RDF-S) by providing additional vocabulary along with formal semantics.
In the present case study, the model has been applied for 10 alternative scrap shears made by 7 well-known European and American manufacturers. The criteria for making the selection are 16. From them, 11 are based on *technical specifications* and 5 are based on *commercial* ones and they are presented in Tables 1 and 2 respectively together with their importance for the required value. From these tables, one can mention the following:

- The 11 *technical specifications* chosen cover almost all technical features of a hydraulic shear.
- These 11 technical specifications can be classified in 3 groups, as follows:
  - Group I, technical specifications of *Power*, including: Hold Down Force (i=1), Force of Side Press (i=2), Lid Cover Force (i=3), Power Ram Force (i=4) and Installed Power (i=11).
  - Group II, technical specifications of *Capacity*, including: Average Estimated Capacity (i=5) and Shearing Capacity (i=6). The last technical specification is the average amount of shearing capacity in rounds, in squares and in plates.
  - Group III, technical specifications of *Size*, including: Throat Width (i=7), Dimensions of Pre-compression Box (i=8), Dimensions of Loading Platform (i=9) and Weight (i=10).
- The 5 *commercial specifications* chosen correspond to features of a hydraulic shear that have to be evaluated more or less subjectively. This is the reason why the *Level of Automation*, while it is rather a technical specification than a commercial one, it is examined with the commercial specifications (it cannot be expressed with a numerical value and an arbitrary scale is needed).
- These 5 commercial specifications can be classified in 2 groups, as follows:
  - Group IV, commercial specifications of *After Sales Service*, including: Cost of Service (j=2) and Guarantee period (j=4). The
first of these two specifications is the average amount of the cost of the necessary spare parts for emergency and the cost of the necessary spare parts for two years operation.

- Group V, commercial specifications of Reliable Operation, including: Level of Automation (j=1), Reputation of the supplier and References i.e. number of installed shears in Europe (j=3) and Condition i.e. totally new or used (as it is) or used and rebuilt (j=5). The features that indicate the first commercial specification (Level of Automation) are the following (with their relevant importance): Auto-return of Pistons (mandatory), PLC Operation (mandatory), Indexing of Cutting (optional), Remote Control (desirable), Automatic Lubrication (desirable), Monitoring of Operation (future) and Material Ejection (optional).

- All together the 16 technical and commercial specifications chosen here aim to describe, in the best possible accuracy, the examined shears, covering areas that concern their power, capacity, size, operation and service.

- The selection of the required values and their importance has been based mainly on the following criteria:
  - The needs of the final user of the equipment.
  - The experience about the process and this kind of equipment.
  - The available literature about the process and this kind of equipment.

For the last two criteria, the assistance of a technical consultant has been employed.

Table 1

Table 2

Figure 2 shows the required specifications of the hydraulic scrap shear as ontology instances.
Figure 2

The actual values of the *technical specifications* \((TS_{i,k})\) and the *commercial specifications* \((CS_{j,k})\) for the candidates scrap shears are given in Tables 3 and 4 respectively.

Table 3

The selection process is based on a scoring methodology, which has been developed to aid in screening and selecting the best equipment from a set of possible alternatives. The criteria for making this screening and selection are the *technical* and *commercial specifications* of each candidate. The methodology distinguishes the specifications in technical and commercial because the first ones are, almost always, tangibles, while some of the last ones are, very often, intangibles. In other words, most of the technical specifications of equipment (like motor power, dimensions, capacity, weight etc.) as well as several of the commercial ones (like price, guarantee, cost of service etc.) could be expressed by numerical values, while also exist other commercial characteristics (like reputation of the constructor, references etc.) that could not. Therefore, each of these last criteria (intangibles) has to be evaluated more or less subjectively, and scored using an appropriate scale. Since this scale is arbitrary, the significance of the criteria based on commercial characteristics have lower weighing factor than the tangible ones based on technical specifications. Obviously, the total number of criteria (technical and commercial) that can be used is unlimited and it is determined by the demands of each case.

Table 4

Finally, applying the selection procedure, the *relevant price* \(R_k\) for each candidate arises (table 5). From the last table, it is obvious that the best option is the scrap shear “J” which has the lowest *relative price* \(R_k\).
More details about this methodology, as well as about its application in the present case study, can be found elsewhere (Georgakellos, 2005).

5. The user interface of the knowledge management framework

In the previous sections the proposed technology selection approach was used in order to evaluate prospective vendors’ equipment, rank the proposals and select the optimum hydraulic scrap shear from the ones offered.

But this is not the only advantage of the approach. An additional advantage is that the knowledge found in the selection process, i.e. the logic, the flow itself and the ways it is used for equipment purchasing, is captured and represented as an ontology-based knowledge management framework. The ontology repository contains all the relative concepts and the relations between them (figure 1). The content repository contains all relevant supportive material (from the entire selection process), in the form of multimedia objects (e.g. text, image, video and animation), that are related to the knowledge domain under consideration (technology selection). Finally the knowledge repository contains all the detailed case specific knowledge (specification requirements and detailed specifications per equipment offered per vendor), i.e. it relates specific instances (e.g. RFP or vendor specifications) of the basic entities defined in the ontology (the specifications hierarchies) with the various supportive multimedia objects. The knowledge repository contains collections of related instances and we can refer to these collections as scenarios. So for the specific case, eleven scenarios were entered, one with the specifications requested (figure 2) and ten (one per prospective) with the specifications offered. As a result, the user is enabled to search for an ontology construct (for example an equipment specification) and understand its meaning and usage with the
help of the supportive multimedia. Furthermore, the user can navigate to associated ontology constructs in order to acquire an in depth knowledge about technology selection processes, the data and control flows between them and how they can be combined in order to solve specific real-life problems, like the hydraulic scrap shear selection process.

Figure 3

Figure 3 shows the users’ interface of the model. The user has two options: (1) chose one of the scenarios (in this case the requested specifications) and navigate through concept instances and relations or (2) search for a concept instance, in which case the system displays all occurrences of the concept instance in all scenarios and then select a specific scenario to navigate. When selecting an instance (for example *Hold Down Force*) the system displays its properties and all supportive multimedia associated with the specific instance. So the user can discover in the properties window (on the left): (1) all the scenarios (pages) where the specific instance appears, (2) comments explaining its use, (3) the ontology-defined concept (*Power*) for the instance (*Hold Down Force*) and (4) all the relations defined for the specific instance in relation to other instances. The user can also navigate into the supportive multimedia (in the specific example a photograph) and find additional information about the instance under consideration.

6. Discussion and Concluding remarks

In this paper, a knowledge management framework for the support of equipment purchasing was presented. The proposed framework addresses the technology selection problem through an ontology-based approach that captures and makes reusable the equipment purchasing process and assists in identifying (a) the specifications requested by the users’ organization, (b) those offered by various candidate vendors’ organizations and (c) perform
specifications gap analysis in combination with a scoring methodology as a prerequisite for effective and efficient technology selection.

The approach utilizes three repositories: (a) the ontology repository that contains all the relevant concepts (high level specifications) and the relations between them, (b) the content repository that contains all relevant supportive material (from the entire selection process) and (c) the knowledge repository that contains all the detailed case specific knowledge (specification requirements and detailed specifications per equipment offered per vendor).

The proposed approach enhances and empowers existing knowledge representation methodologies by allowing the semantic representation of knowledge so that to enable users navigate into the underlying knowledge of the application domain (technology selection) under consideration. Thus, the model can combine the existing multimedia material with ontology constructs, in order to build case specific scenarios and satisfy specific technology selection needs. Hence, in addition to the existing multimedia objects, the knowledge built into both the ontology and the scenarios is fully reusable (Macris, 2011).

One of the deliverables of the approach is an ontology-based, organization-wide technology selection assessment model (a taxonomy), based on the specifications required by various technology selection functions and organizational positions. This taxonomy can be used and enriched to further support the technology selection process in various situations and environments.

The combination of gap analysis and scoring methodology proposed has been developed intending to provide a tool that may be more convenient and helpful in various projects of equipment purchasing, such as to sort (or exclude) the candidate equipment and technologies in the pre-qualification phase, or the final choice phase of the selection process.

The scoring methodology proposed combines the principles of the linear weighting models and the total cost of ownership models. The model
intends to help decision-making in a clear and simple way, while its algorithm can be easily computerized using a common spreadsheet and not specific software. In addition, this scoring model takes into account the tradeoffs among the criteria as defined by the relative weights, as well as it seems to be adaptable to almost any case in the manufacturing sector and especially the iron and steel industry (Georgakellos, 2005).

Complementary to the theoretical presentation of the model, an example of a technology selection project is also presented in the paper to illustrate the proposed framework. It is a real application that concerns an equipment-purchasing project in the iron and steel industry. In this case study, the model has been successfully applied helping the decision makers to obtain a final ranking of the alternative equipment and to select the option that seems to be the best. Based on this case study, an evaluation of the model is realized. The overall picture of the model, according to the findings of this evaluation, is encouraging. Briefly, the proposed model seems to be sufficiently user-friendly, clear and flexible, processing available information correctly and resulting in acceptable outcome that facilitates communication, presentation, knowledge reuse and justification of the decision. However, it is strongly proposed that more applications of the model be made in the future, to better demonstrate its advantages and disadvantages through additional practice.
References


CVs

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Tables
Table 1: Technical specifications and their importance for the required value

<table>
<thead>
<tr>
<th>i</th>
<th>Technical Specification i</th>
<th>Value</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hold Down Force</td>
<td>≥ 200 MT</td>
<td>Mandatory</td>
</tr>
<tr>
<td>2</td>
<td>Force of Side Press</td>
<td>≥ 300 MT</td>
<td>Desirable</td>
</tr>
<tr>
<td>3</td>
<td>Lid Cover Force</td>
<td>≥ 200 MT</td>
<td>Mandatory</td>
</tr>
<tr>
<td>4</td>
<td>Power Ram Force</td>
<td>≥ 100 MT</td>
<td>Desirable</td>
</tr>
<tr>
<td>5</td>
<td>Average Estimated Capacity</td>
<td>≥ 15 MT/hr</td>
<td>Mandatory</td>
</tr>
<tr>
<td>6</td>
<td>Shearing Capacity</td>
<td>≥ 150x150x</td>
<td>Desirable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100x100 mm</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Throat Width</td>
<td>≥ 700 mm</td>
<td>Mandatory</td>
</tr>
<tr>
<td>8</td>
<td>Dimensions of Pre-compression</td>
<td>≥ 6x2 m</td>
<td>Mandatory</td>
</tr>
<tr>
<td></td>
<td>Box</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Dimensions of Loading Platform</td>
<td>≥ 5x2 m</td>
<td>Optional</td>
</tr>
<tr>
<td>10</td>
<td>Weight</td>
<td>≥ 200 MT</td>
<td>Desirable</td>
</tr>
<tr>
<td>11</td>
<td>Installed Power</td>
<td>≥ 350 kW</td>
<td>Desirable</td>
</tr>
<tr>
<td>j</td>
<td>Commercial Specification j</td>
<td>Value</td>
<td>Importance</td>
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<tr>
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<td>----------------------------</td>
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<td>------------</td>
</tr>
<tr>
<td>1</td>
<td>Level of Automation</td>
<td>Selected Features $^a$</td>
<td>M/M/O/ D/D/F/O $^b$</td>
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<tr>
<td>2</td>
<td>Cost of Service $^c$</td>
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<td>Desirable</td>
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<tr>
<td>3</td>
<td>Reputation and References</td>
<td>$\geq 2$</td>
<td>Optional</td>
</tr>
<tr>
<td>4</td>
<td>Guarantee period</td>
<td>$\geq 6$ months</td>
<td>Mandatory</td>
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<tr>
<td>5</td>
<td>Condition</td>
<td>New</td>
<td>Optional</td>
</tr>
</tbody>
</table>

$^a$ Auto return of pistons / PLC operation / Indexing of cutting / Remote control / Automatic lubrication / Monitoring of operation / Material ejection

$^b$ M = Mandatory / D = Desirable / O = Optional / F = Future

$^c$ Cost of spare parts for emergency (€) / Cost of spare parts for 2 years operation (€)
<table>
<thead>
<tr>
<th>Candidate</th>
<th>TS(_{1,k})</th>
<th>TS(_{2,k})</th>
<th>TS(_{3,k})</th>
<th>TS(_{4,k})</th>
<th>TS(_{5,k})</th>
<th>TS(_{6,k})</th>
<th>TS(_{7,k})</th>
<th>TS(_{8,k})</th>
<th>TS(_{9,k})</th>
<th>TS(_{10,k})</th>
<th>TS(_{11,k})</th>
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<tr>
<td>A (k=1)</td>
<td>320 (MT)</td>
<td>320 (MT)</td>
<td>220 (MT)</td>
<td>100 (MT)</td>
<td>27.0 (MT / hr)</td>
<td>195 / 175 / 120 x 900</td>
<td>1000 (mm)</td>
<td>6 x 2.2 x 1.25</td>
<td>no</td>
<td>219.5 (MT)</td>
<td>470 (kW)</td>
</tr>
<tr>
<td>B (k=2)</td>
<td>310 (MT)</td>
<td>310 (MT)</td>
<td>120 (MT)</td>
<td>25.0 (MT)</td>
<td>190 / 170 / 100 x 100</td>
<td>600 (mm)</td>
<td>6 x 2 x 0.9</td>
<td>6 x 2.5</td>
<td>210.0 (MT)</td>
<td>380 (kW)</td>
<td></td>
</tr>
<tr>
<td>C (k=3)</td>
<td>310 (MT)</td>
<td>400 (MT)</td>
<td>125 (MT)</td>
<td>27.0 (MT)</td>
<td>200 / 180 / 110 x 980</td>
<td>800 (mm)</td>
<td>8 x 2.55 x 1.75</td>
<td>8 x 2.5</td>
<td>230.0 (MT)</td>
<td>580 (kW)</td>
<td></td>
</tr>
<tr>
<td>D (k=4)</td>
<td>250 (MT)</td>
<td>339 (MT)</td>
<td>470 (MT)</td>
<td>18.0 (MT)</td>
<td>190 / 167 / 105 x 863</td>
<td>940 (mm)</td>
<td>7.9 x 2.4 x 0.8</td>
<td>7.9 x 1.8</td>
<td>198.0 (MT)</td>
<td>248 (kW)</td>
<td></td>
</tr>
<tr>
<td>E (k=5)</td>
<td>200 (MT)</td>
<td>250 (MT)</td>
<td>250 (MT)</td>
<td>100 (MT)</td>
<td>24.0 (MT)</td>
<td>185 / 175 / 120 x 700</td>
<td>850 (mm)</td>
<td>6.1 x 2.25 x 2</td>
<td>no</td>
<td>185.0 (MT)</td>
<td>371 (kW)</td>
</tr>
<tr>
<td>F (k=6)</td>
<td>160 (MT)</td>
<td>300 (MT)</td>
<td>250 (MT)</td>
<td>100 (MT)</td>
<td>24.0 (MT)</td>
<td>195 / 175 / 120 x 700</td>
<td>800 (mm)</td>
<td>7.1 x 2.25 x 2</td>
<td>no</td>
<td>225.0 (MT)</td>
<td>375 (kW)</td>
</tr>
<tr>
<td>G (k=7)</td>
<td>120 (MT)</td>
<td>720 (MT)</td>
<td>no(^d)</td>
<td>120 (MT)</td>
<td>18.5 (MT)</td>
<td>na / na / na</td>
<td>na (mm)</td>
<td>6.2 x 2.3 x 1.3</td>
<td>no</td>
<td>80.0 (MT)</td>
<td>373 (kW)</td>
</tr>
<tr>
<td>H (k=8)</td>
<td>350 (MT)</td>
<td>600 (MT)</td>
<td>300 (MT)</td>
<td>200 (MT)</td>
<td>32.5 (MT)</td>
<td>na / 167.5 / na</td>
<td>950 (mm)</td>
<td>6.6 x 2.3 x 1.8</td>
<td>no</td>
<td>255.0 (MT)</td>
<td>450 (kW)</td>
</tr>
<tr>
<td>I (k=9)</td>
<td>250 (MT)</td>
<td>na(^e)</td>
<td>no</td>
<td>na</td>
<td>na</td>
<td>na / na / na</td>
<td>1100 (mm)</td>
<td>7.5 x 2.7 x na</td>
<td>no</td>
<td>na (MT)</td>
<td>360 (kW)</td>
</tr>
<tr>
<td>J (k=10)</td>
<td>200 (MT)</td>
<td>310 (MT)</td>
<td>310 (MT)</td>
<td>155 (MT)</td>
<td>24.0 (MT)</td>
<td>200 / 180 / 110 x 110</td>
<td>800 (mm)</td>
<td>8 x 2 x 0.9</td>
<td>8 x 3.3</td>
<td>220.0 (MT)</td>
<td>480 (kW)</td>
</tr>
</tbody>
</table>

\(^a\) Rounds / Squares / Plates (L x W)  
\(^b\) L x W x H  
\(^c\) L x W  
\(^d\) no = the specification does not exist in the candidate  
\(^e\) na = data not available
### Table 4: Commercial specifications “CS<sub>j,k</sub>”

<table>
<thead>
<tr>
<th>Candidate</th>
<th>CS&lt;sub&gt;j,k&lt;/sub&gt;&lt;sup&gt;a&lt;/sup&gt;</th>
<th>CS&lt;sub&gt;2k&lt;/sub&gt;&lt;sup&gt;b&lt;/sup&gt;</th>
<th>CS&lt;sub&gt;1k&lt;/sub&gt;</th>
<th>CS&lt;sub&gt;3k&lt;/sub&gt;&lt;sup&gt;c&lt;/sup&gt;</th>
<th>CS&lt;sub&gt;4k&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (k=1)</td>
<td>y/y/y/y/n/n</td>
<td>18 250 / 73 000</td>
<td>32</td>
<td>6</td>
<td>new</td>
</tr>
<tr>
<td>B (k=2)</td>
<td>y/y/n/o/y/n/n</td>
<td>9 150 / 36 500</td>
<td>20</td>
<td>12</td>
<td>new</td>
</tr>
<tr>
<td>C (k=3)</td>
<td>y/y/y/y/y/y</td>
<td>9 150 / 36 500</td>
<td>20</td>
<td>12</td>
<td>new</td>
</tr>
<tr>
<td>D (k=4)</td>
<td>y/y/y/y/n/n</td>
<td>17 750 / 71 000</td>
<td>0</td>
<td>12</td>
<td>new</td>
</tr>
<tr>
<td>E (k=5)</td>
<td>y/y/n/o/y/n/n</td>
<td>9 256 / 46 280</td>
<td>4</td>
<td>12</td>
<td>new</td>
</tr>
<tr>
<td>F (k=6)</td>
<td>y/y/n/o/y/n/n</td>
<td>10 700 / 53 500</td>
<td>3</td>
<td>12</td>
<td>new</td>
</tr>
<tr>
<td>G (k=7)</td>
<td>y/y/n/y/n/n</td>
<td>6 200 / 31 000</td>
<td>na&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6</td>
<td>new</td>
</tr>
<tr>
<td>H (k=8)</td>
<td>y/y/n/o/y/n/n</td>
<td>18 200 / 72 700</td>
<td>na</td>
<td>12</td>
<td>new</td>
</tr>
<tr>
<td>I (k=9)</td>
<td>y/y/n/o/y/n/n</td>
<td>5 850 / 29 200</td>
<td>na</td>
<td>12</td>
<td>new</td>
</tr>
<tr>
<td>J (k=10)</td>
<td>y/y/y/y/n/n</td>
<td>9 150 / 36 500</td>
<td>20</td>
<td>9</td>
<td>rebuilt</td>
</tr>
</tbody>
</table>

<sup>a</sup> Auto return of pistons / PLC operation / Indexing of cutting / Remote control / Automatic lubrication / Monitoring of operation / Material ejection

<sup>b</sup> Cost of spare parts for emergency (€) / Cost of spare parts for 2 years operation (€)

<sup>c</sup> Months

<sup>d</sup> y = yes / n = no / o = optional

<sup>e</sup> na = data not available
Table 5: The Relative Price “$R_k$” for each candidate technology

<table>
<thead>
<tr>
<th>Candidate</th>
<th>$R_k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (k=1)</td>
<td>2 116 134.2</td>
</tr>
<tr>
<td>B (k=2)</td>
<td>1 208 751.0</td>
</tr>
<tr>
<td>C (k=3)</td>
<td>1 403 556.0</td>
</tr>
<tr>
<td>D (k=4)</td>
<td>2 026 742.0</td>
</tr>
<tr>
<td>E (k=5)</td>
<td>1 327 770.8</td>
</tr>
<tr>
<td>F (k=6)</td>
<td>1 514 870.5</td>
</tr>
<tr>
<td>G (k=7)</td>
<td>1 225 198.1</td>
</tr>
<tr>
<td>H (k=8)</td>
<td>1 490 143.0</td>
</tr>
<tr>
<td>I (k=9)</td>
<td>1 852 823.9</td>
</tr>
<tr>
<td>J (k=10)</td>
<td>859 726.6</td>
</tr>
</tbody>
</table>
Figures
Fig. 1. Technology selection ontology concepts. A (high level) general specifications’ model applicable to all technology selection processes.
Fig. 2. The (low level) case specific specifications (instances, referring to higher level specifications – concepts) for the hydraulic scrap shear as they appear in the RFP.
Fig. 3. The user’s interface where the user can navigate into scenarios (RFPs or vendors offers), examine (case specific) instances (and the high-level concept per instance), instance relations with other instances and supportive multimedia per instance.