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Modeling Quality knowledge to design log sorting system by X rays tomography

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Abstract: The aim of this paper is to highlight the advantage of using human (expert) knowledge and know-how to design an automated quality control system. This study is based on an industrial case of a French sawmill. The modeling deals with qualitative analyses of round wood and sawn timber in order to tune X rays scanner system. NIAM/ORM method is used to model quality expert knowledge. It enables to establish existing or missing links in one quality or between different levels of quality. This model will improve the optimization of one or several decision methods based on experts' knowledge of the company.

Key words: *Quality control, X rays scanner, Knowledge modeling, NIAM/ORM.*

1. INTRODUCTION

Sawyer trade evolved since its creation. Sawyer tries to have a good material promotion in yield term and in qualitative term as well. In order to do that, sawmill is supplied with long stem (tree without branches) that it valorizes in short log, its selves sawed in final products responding to quality and dimensional requirements of the customers.

Trade evolution affects the methods of forest management moreover. These methods can differ in function of the country uses, the historical planting of its territory, the directions chose by all the chain after major events (crisis, storms ...). In France, methods of forest management make supply heterogeneous in diameters, lengths, species, and even intrinsically to the wood. Effectively, wood is a living heterogeneous material because of its (1) gene pool (from specie to another), (2) its geographical localization (coordinates of the planting), (3) its stational situation (ground and sunshine of the tree) and (4) the area of the considered tree (butt end log to top end log). External events add to this natural heterogeneity. Insect attacks, storms, pruning, fungus attacks or animal's damage affect tree behavior, its structure and therefore, its quality. French sawmill uses this supply at the best, in order to take care and promote all parts of the stem.

Input of French sawmills production process is a heterogeneous material intrinsically and a heterogeneous supply. In process output, sawmills are confronted with customers who want to have a homogeneous quality in product-to-product and parcel-to-parcel regardless where the wood comes from (except for certification aspect). Sawmill implements quality sort out on different levels of the production chain to surpass these constraints. The chain of the studied sawmill is represented by the block schema Fig. 1 in which "Log yard" block is detailed.

The study presented in this paper is exclusively restricted to the *qualitative analysis* to optimize the stem in log. However, such analysis begins with getting pertinent information that enables to define wood characteristics: the paper includes

definition of data given by the *acquisition* module. In addition, qualitative analysis evaluating the best sawing pattern is the sawmills main work (and secret) and it is the first factor of theirs customer. Due to this factor, the paper will describe industrial production means only like a state of art and the results will be shown partially in the following section.

Continuous improvements of the sawmill lead to create an automated log yard. In addition to the mechanizations which enable a right flexibility of supply, the log yard is equipped with a multi-sensors vision system that adds an external analysis and also an internal analysis of the stem according to the production chain speed.

The purpose of the study is to present the expended means to exploit data given by vision system. Our objective is to integrate knowledge in the decision system, as done in [Bombardier V., 2007]. The decision system becomes a useful support for the production operator who takes the final decision. The first step is to establish a model of "Wood quality". This quality model will enable to define quality criteria and be able to manipulate them in a "Quality" decision system. Originality of this study is that model provides from a downward approach (from operators or managers) (compare to the usual upward approach from scanning data). The purpose is to minimize the set-up time of the system. This model will be complete after, once the scanner set up on site.

For do it so, section 2 shows the studied system as a state of art, section 3 develops used analysis method to modeling and section 4 is focused on the first partial results. The conclusion explains our next works to integrate the knowledge into the (semi)-automated system.

2. DATA ACQUISITION SYSTEM

For more than twenty years, wood industries have used non-contact vision system in their production process. System performances help human decisions and sometimes enable to replace him. They give a better reliability, repeatability,

accuracy or/and production rate [Buehlmann U., 2002]. In another hand, those systems make it possible to access to information that naked eyes cannot detect. Microscopic and internal views of the material are possible by non-destructive and fast means. Sensors are mainly linked to surface analysis in furniture industries, cabinet making, laminated wood (for the color) and structural analysis in building industries too.

For example, when camera is combined to laser system, it is able to measure wood texture using reflectance. Vision systems using such sensors have good performances regarding surface analysis, as well as production rate as recognition rate. On sawing product, it is possible to accurately detect, localize and measure wood defects such as black knots, sound knots, resin pockets, compression wood, colored wood, blue stain or waness [Deng J.D., 2007; Bombardier V., 2007]. Results obtained on surface analysis with camera are equal to ones obtained with X rays scanner. In addition to this, for this type of analysis, cameras make it possible to visualize color that no other sensor can measure. These properties are used in color sort out applications [Faria J., 2008; Bombardier V., 2009].

X rays scanners can also achieve aspect analysis but they are mainly used for structural analysis. X rays penetration enables to visualize internal wood defects. The accuracy of industrial sensor, at 2 or 3 meter/second production rate, did not enable to localize and to measure accurately knots or others defects. However, studies about algorithms show that detection, localization and quantification of knots in a short log are possible and reliable with a sufficient accuracy [Longuetaud F., 2004 & 2005; Entacher K., 2007a & 2008; Oh J.K., 2009]. Recent progress done in X rays scanners oriented scientific research through image processing. Effectively, scanners now offer enough accuracy to defect recognition but some of them are not industrially viable because the acquisition speeds are still too slow.

Structural analysis finds most of its application in images reconstruction in two or three dimensions which enables to obtain supplementary information: the shape. Shapes of defect have an essential role in their detection and their identification (labeling). Structural analysis aims to internal defects detection, which is possible with X rays or gamma rays scanners. X rays scanners appeared to be the most promising tool in the preliminary studies that is why most researches were conducted on that kind of scanner [Oja J., 2003; Longuetaud F., 2005 & 2007; Entacher K., 2007a & 2007b]. There are three main types of X rays scanner: 2D, 4D and CT (Computed Tomography). 2D and 4D are respectively composed by two X rays sources at 90° or four sources at 36°. Those scanners give two (for 2D) or four (for 4D) images in two dimensions to analysis. CT enables several projected views by rotation of the source or by rotation of the piece (until 720 images at the moment). Then, projected views are combined to reconstruct the item en tree dimensions. 2D and 4D scanners are the ones mainly used in wood industries because their processing times are shorter. Recently, CT scanners get into industries due to their improvements on reconstruction algorithms. Detection results depend mainly on detection algorithms because scanner accuracy is now sufficient. Once defects are detected,

structural analysis could be improved by correlating wood defects to quality [Wei Q., 2009] or wood strength [Brännström M., 2007].

Vision systems are able to give reliability information to following module [Rojas G., 2006]. In that way, the main industrial issue is not only to obtain information but also to define (1) which the pertinent information are regarding objectives and (2) how to use them in order to automate actions made by human beings and based on their experience. The answer of these two issues is given and integrated by the module of *qualitative analysis* (cf Fig.1). This module must hold experience knowledge owned by the company, and needed to set up and integrate the vision system. Another difficulty consists in taking into account this knowledge and transcript it to the control system. This implies a strong work relationship between experts in several domains (quality, computer programming, optimization...). It is necessary that all actors of the study have the same understanding of the system to reach goals. Developing a model of wood quality knowledge at different levels of the production chain is the best way to define problems. It can lead to a specific ontology creation to enable collaboration between actors implementing the system.

Achievement of different quality models of the company enables to (1) establish links between different levels of quality; (2) specify quality really used or planned in the future; (3) define input information of *qualitative analysis* in the new system; (4) select an adapted computed decision system and (5) set up the decision system.

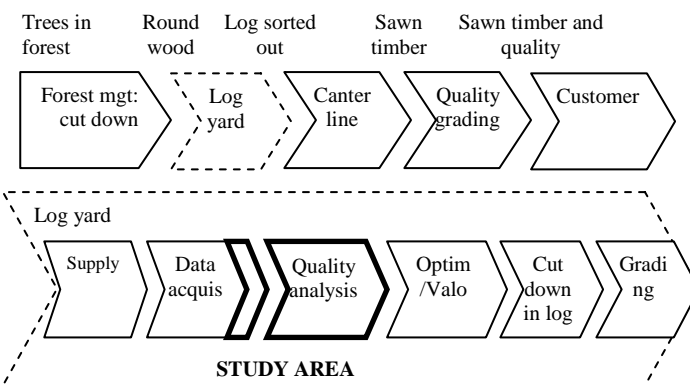


Fig. 1. Schema of sawmill production chain and detailed schema of “Log yard”

3. KNOWLEDGE MODELING

To capitalize sawyer’s know-how, useful in the achievement of the control system, Natural language Information Analysis Method (NIAM) is used [Blaise J.C., 2003]. It enables to model beginning with a knowledge express in natural language. Moreover, the ORM (Object Role Modeling) formalism is used to write the model. After presenting the main knowledge modeling principles and methods, we will describe NIAM in this section.

3.1 Modeling principles

Main difficulties in model conception are the acquisition of information (more in the tacit domain) and the fact that

information is owned by several experts (merge overall to reach one final objective). Achievement of a system using knowledge follows three processes that it makes possible to pass from a tacit informal knowledge to an explicit formal knowledge usable by all the actors. These three processes are: (1) acquisition of knowledge; (2) formalization of knowledge and (3) mining of modeling knowledge (cf. Fig 2). This paper mainly concerns the couple acquisition/formalization of knowledge but expresses possible ways for knowledge mining in future works (Cf. Discussion and conclusion).

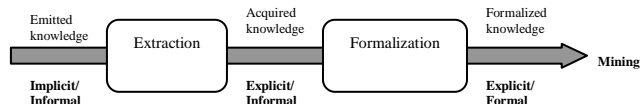


Fig. 2. Process to construct system using knowledge

3.1.1 Acquisition of knowledge

Operator or manager's knowledge is implicit (tacit) for himself. It means that when he expresses it, the terms he uses can be ambiguous or refer to a knowledge non-known by everyone. The transmission of information in industrial domain is mainly done in natural language. This language is quasi-perfect between humans [Andrade J., 2006] but it shows limitations in some situations. Several sources could distort expressed knowledge: (1) constitution itself of the language which can be ambiguous in function of the complexity or the specificity of expertise area; or (2) the use of indirect means to express knowledge (synonyms, neighbor concepts, intermediate level of abstraction) which lead to an approximation of the knowledge.

Two approaches are usually distinguished to acquire knowledge: manual approaches (or knowledge engineering approaches) and automated approaches based on software engineering. Knowledge engineering approaches imply the use of interview techniques based on psychology works. Among these methods, we can count: interviews, verbal protocol analysis done by live-record of expert during problem resolution, direct observation, the use of questionnaire, and brainwriting. Automated approaches aim to highlight a significant knowledge based on a large data base.

In this study, knowledge engineering methods are mainly used. Knowledge engineer interviewed production operators and managers and he followed training session about sales, wood quality, wood supply and forestry as well. Knowledge becomes explicit informal.

3.1.2 Formalization of knowledge

This step purpose is to transform an explicit informal knowledge into an explicit formal knowledge. Three approaches can be used to extract knowledge in a structured way: upward approach, downward approach and mix approach. Upward approach implies that knowledge engineer collects as many information as possible without leading or influencing the interviewed expert. Model is built by successive addition of information (iterative construction). Whereas, downward approach leads the engineer directly to the final model definition screening-off the knowledge and lead efficient acquisition process; knowledge engineer must

be skilled in expertise system. Mix approach combines upward approach first and downward approach then in the same formalization. Mix approach is used in this study.

Model construction is based on acquisition and formalization of knowledge. Related to the concerned area, conceptual modeling uses different forms of natural language. Structural document analysis is mostly used to recognize entities and relations between them. Another form uses linguistic area to build a conceptual model and makes sure that model content is led by specifications in natural language. Finally, natural language is the best mean to communicate because, in that case, it is the only comprehensible language by all project actors. Natural language is an essential factor of this study.

Several formalization methods using natural language are explained in literature. We cite Natural language Information Analysis Method (NIAM) known as NIAM/ORM due to its derivative formalism ORM (Object Role Modeling) [Blaise J.C., 2003], Conceptual Graphs (CG) [Dibie-Barthélemy J., 2006], Object Conceptual Prototyping Language (OCPL) [James A.E., 2000]. Moreover, softwares are developed to acquire information from a domain and/or build an associated model. These tools use natural language processing elements which analyze texts and extract pertinent information to construct searched ontology. Textual analysis is based on syntax relations between terms.

Each mentioned method explains its own ontology building an approach of the domain. However, none of them gives information about the model validity. Wagner JC [Wagner J.C., 1999] created modules able to translate conceptual models into natural language to (1) validate knowledge models with formalism close to the natural language and to (2) re-use modeling knowledge without being an expert of the used formalism. It's in the same way that NIAM enables an easy translation into natural language, comprehensible by layman and wherein (manual) generation has to be done by knowledge engineer.

In this study, NIAM/ORM is used: others methods are either (1) too specific of an area and need to be modified by external tools to be compatible, or (2) use formalism of which legibility is not easy and its utilization is not natural (CG and OPCL approaches), or (3) are associated with a transcription tool which is too complex and not very efficient. The simplicity of transcription tool is the main asset of NIAM/ORM, moreover, it is easy to use and to implement.

3.2 NIAM/ORM modeling method

The main purpose of this method is to analyze knowledge from a specific area (named Speech Universe or Interest Universe). In order to make this, this method uses a descriptive language from the real world in term of objects playing roles. Asset of ORM formalism, compared to the most known UML (United Modeling Language), is its ability to express information with simple relations; it is the real leitmotiv of NIAM. The method distinguishes Interest Universe on two systems: the object system and the abstraction system (see Fig. 3).

Modeling method reasoning is based on three axioms ensuring the quality of the obtained model: (1) semantic

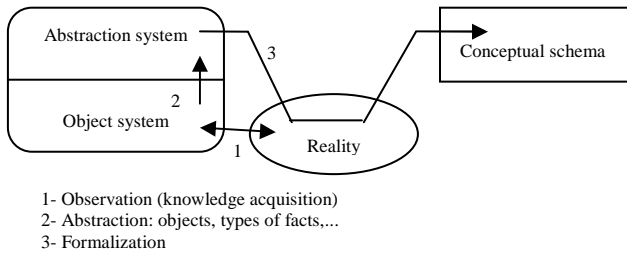


Fig. 3. Object and abstraction system following NIAM/ORM method.

matching between facts in natural language and several elementary sentences; (2) elementary sentence expressions highlight “idea” and “denomination bridge”; and (3) determination of all possible conditions and all enabled transitions in the data base.

Elementary sentence is a sentence which cannot be decomposed in shorter sentence without loss of semantic. These decompositions enable to minimize ambiguities, minimize shortcut inherent to natural language use. Ideas and denomination bridges respectively represent links between two abstract objects and, links between abstract objects and the objects they represent in the reality. Ideas carry information contained (and needed) in the conceptual model. Denomination bridges do not carry information: they only help to represent real part of Interest Universe in the final data base. Finally, constraint additions on objects composing an idea must be done to be sure about the coherence between modeling knowledge and observed facts.

In practice, NIAM/ORM is deployed in four steps: (1) acquisition of knowledge; (2) modeling of knowledge; (3) model validation and (4) formalized knowledge validation. This paper deals with knowledge acquisition and modeling. At the moment, the validation is done by the production experts (sawmill operators and managers). After, a final validation will be done by data analysis provided by the vision system. Moreover, due to confidentiality terms, following presented results are under-group or part of global model.

4. “QUALITY” MODELS AND ANALYSES

This section describes NIAM/ORM application to our study case. It aims to give “Sawn timber quality” and “Log quality” knowledge models which will be mine during set up stage of the vision system.

4.1 Acquisition of expert knowledge in wood grading

Mix approach is used in this extraction of knowledge. Upward approach is done by a training of the knowledge engineer in expertise area. He integrated production shift which realize wood grading. This training is made in all workstations of the factory where a quality decision is taken: on round wood and on sawn wood. Moreover, theoretical training is done by others company department (commercial, strategic, purchase) and enhanced practical training. Those enable to understand instructions given to production department. Knowledge engineer is able to specify wood quality according to his direct observations and his own comprehension of the different training. Downward phase

consists in creating a questionnaire given to experts and completed during their interview.

Engineer obtains two different expertises: one on round wood quality and the other one on sawn timber quality. The one on round wood quality aims to express a “log” quality function of physical characteristics on the shape of the stem. Sawn wood quality expresses a “sawn timber” quality function of characteristics visible on the four sides of boards. Engineer extracts whole characteristics from these expertises to define both qualities. These characteristics will be used as decision criteria to final quality sort out.

These two qualities are linked one to the other by geometric or anatomic relations. For example, criterion “visible diameter of dead knot” on the sawn timber is geometrically linked to criterion “diameter of dead knot” of the round timber. This relation takes into account knot form, sawn position in the log, etc. To explain anatomic relation, and due to confidentiality reason, we will name a wood characteristic “Characteristic Y” because it’s extracted from the company know-how. So, as an example, criterion « Presence of embedded bark » evaluated on sawn timber is anatomically linked to criterion “Presence of Characteristic Y” in most cases because this characteristic is often (but not always) associated with embedded bark. Quality modeling highlights existing links inside a quality, existing links between two different qualities, and above all, missing links between qualities. It’s actually this number of missing links that the new log yard tends to reduce.

4.2 Knowledge modeling of wood experts

Log quality experts describe each wood characteristic. They describe for instance a dead knot as follow: “A dead knot is like a dark and round stain in wood surface in most of the case. Otherwise, a dead knot can be light but ringed [surround] by a ring [of bark]. [...]”.

These kinds of definitions use ambiguous terms, so knowledge engineer must use this own knowledge to interpret what experts told him. Following NIAM/ORM method (and the engineer using it), translation in elementary sentences can be: “Dead knot is contrasted to main wood color. Dead knot is round. Dead knot is usually dark. Dead knot can be light. If dead knot is light, it is ringed by bark ring.”

Then, these sentences are translated in their “deeper form”. With the previous example:

- *Dead knot is round* => the wood characteristic “Dead knot” have a form “Round”

Elementary sentences, illustrating real facts, are translated into ORM formalism. For example, following sentences are in Fig. 4: *Dead knot is round. Dead knot is usually dark. Dead knot can be light.*

Using this, knowledge engineer extracts only ideas to obtain basis of generic model. He then can interrogate him-self or asks experts to establish constraints between objects of this model. For example, Question (1) on totality of the object *Wood characteristic*: “Is each *Wood characteristic* defined by a *Form*?”_ Answer: Yes. Question (2) on uniqueness of *Wood characteristic*: “A *Wood characteristic* type *Dead knot*

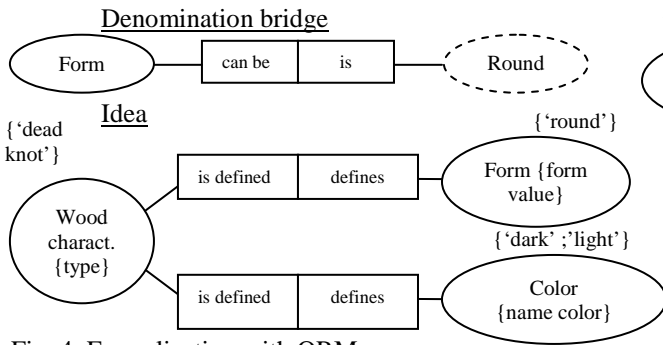


Fig. 4. Formalization with ORM

is defined by one and only one *Form* or by one or several *Forms*?”_ Answer: One and only one. Question (3) on totality of the object *Form*: “Is each *Form* defined a *Wood characteristic*?”_ Answer: No. Question (4) on uniqueness of *Form*: “A *Form* type *Round* defines one and only one *Wood characteristic* or one or several *Wood characteristics*?”_ Answer: One or several. Fig. 5 shows formalization of the answers.

The engineer obtains models for sawn timber quality and for log quality. Parts of models are given Fig. 6. Comparison of both models highlights links between qualities. For example, models given in Fig. 6 highlight direct link between both measures of dead knot diameter (point 1), indirect link between embedded bark measure on sawn timber and characteristic Y measure on log (point 2) and, lack of link between embedded bark of sawn timber and the one of log (point 3). That’s how models support engineer work which aim to reduce number of missing links and also improve coherence of existing links. Links highlighting isn’t automated. Today, only experts can judge link coherence. In this study, major part of criteria (needed to definition of sawn timber quality) could be linked to one or several criteria of the log quality. Missing links concern material deteriorations that are too small to be visible by the vision system or with no effect on the measured material properties. In addition,

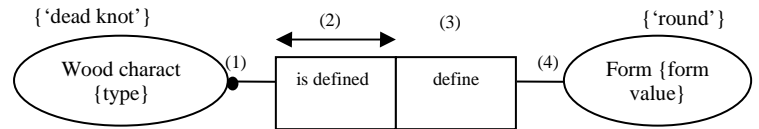


Fig. 5. Formalization of uniqueness and totality constraints

created links are often indirect. They are made either by geometrical correlation or by statistical correlation based on previous scientific studies or on the staff experience. Comparison results of both qualities enable to highlight a new log quality which will be implemented on the log yard. This log quality will be a combination of more than 40 criteria. In addition, beyond the quality definition, modeling highlights characteristics that stem optimization and valorization module (see Fig. 1) have to own (These results will be presented in a next study).

Syntax analyses of definitions given by experts are also expressed in models. A hierarchical organization of criteria appears which highlights structure of the expert’s mind. For example, on a dead knot in the stem: “*Diameter has to be less than 25 mm to a “Q2” quality if the stem diameter is higher than 35 cm on this stem part*”. It’s obvious that expert judges successively (1) a precise part in the stem wherein (2) he evaluates stem diameter to finally (3) evaluate knot diameter regarding stem diameter. Models enable to organize expert decision method into a hierarchical way. However, there is no warranty about effectiveness and efficiency of this structure. In this study, hierarchical structure is established manually but syntax analysis software can generate it automatically. Manual structure establishment takes lot of time and needs a high focusing of the knowledge engineer. He often faces incoherencies or contradictions that he can’t correct by himself. He must refer again to experts who clarify, correct and improve information to surpass this situation. Results show a hierarchical decision of the log quality on 8 levels. Levels directly lead to sought quality or reduced decision range by eliminating impossible quality and

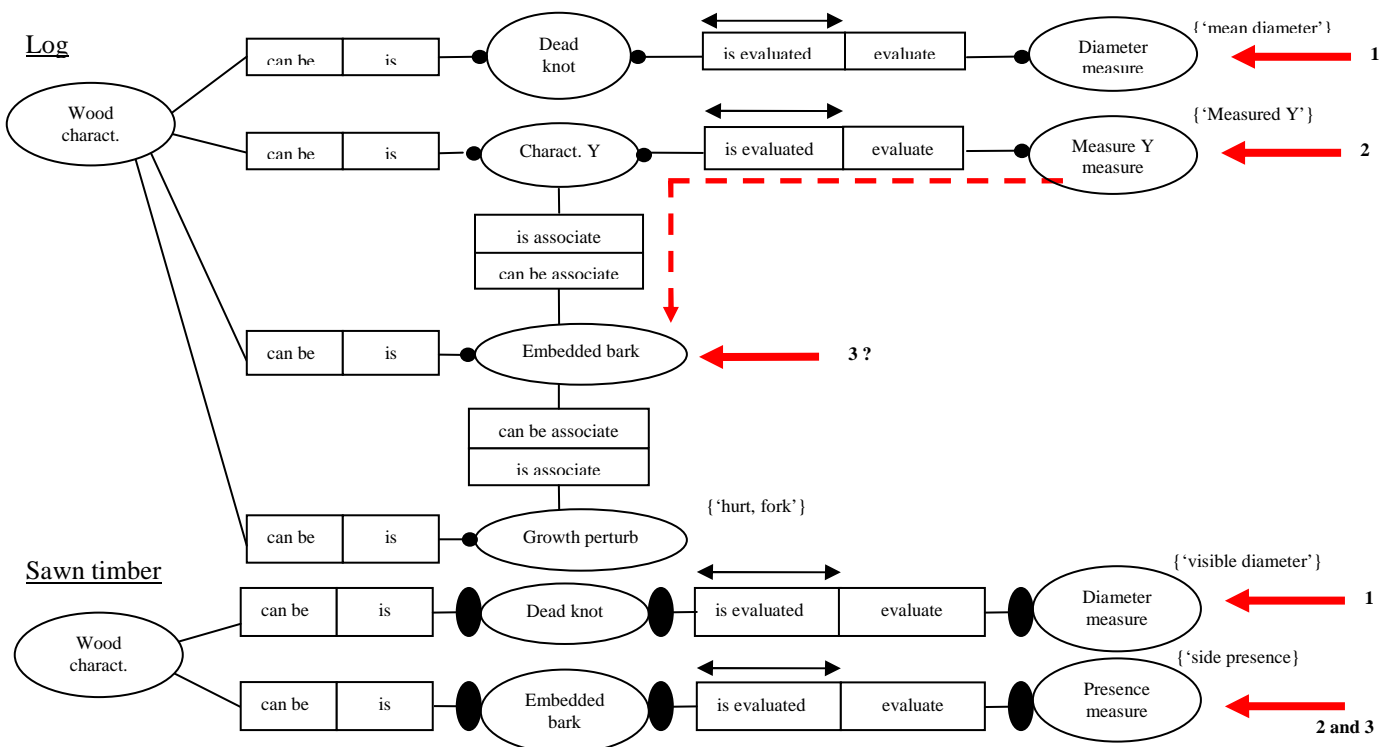


Fig. 6. Partial generic models of sawn timber quality and log quality

lead, step by step, to the final answer.

5. DISCUSSION AND CONCLUSION

Knowledge modeling in an industrial area enables to improve system comprehension of each expert, and also enables a collaborative work between them. Integration of a new expert with a new knowledge or a new point of view at any time is made easier. Beyond the better staff synergy, creating models with NIAM/ORM method enables, a posteriori, a validation of models by all the experts, even the ones who are not familiarize with ORM formalism. In this study, the validation of the model is done by quality experts. The first model is based on human knowledge and its analyses emphasize existing links and missing links inside a quality and between levels of qualities. ORM is currently used to formalize knowledge. That can be considerate as creation of an expert ontology. Such ontology can improve dialogue and comprehension between actors easily. Analyses on the final results will lead to the selection of pertinent criteria, pertinent thresholds and an optimal hierarchical structure of the qualitative decision system. This work enables to capitalize and homogenize quality knowledge and know-how of the company.

At the moment, NIAM/ORM models emphasize criteria needed to define quality and highlight also mind structure of experts who are the owners of knowledge. These works are a strong basis to launch the new system when it will be provided.

Once the system on site, we will be able to compare the decision system (and the knowledge model) to the reality. Data analysis should challenge the decision system and the knowledge model.

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