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ABSTRACT

This paper presents an approximation to a methology to identify the knowledge required in the inspection process planning with coordinate measuring machines. The focus of the work is in the knowledge capitalization, but in particular the phase of elicitation, that is, the process of obtaining knowledge from experts before its formalization and implementation in a system. The application of knowledge based methodologies to other activities different to the design process problem is scarce. In that paper the application is focused to the problem of the design of the inspection process. The inspection planning is a good candidate for implementing a knowledge based engineering system because the repetitive and well-known decisions to make, although almost this knowledge is today implicit in the expert mind. An extension to MOKA methodology together with IDEF0 graphical modelling has been used. The reason is that this methodology is the only one which allows eliciting knowledge from documents within engineering domains through its ontology. The identification of knowledge is done in a first high-abstraction level of approximation which will serve as basis to a detailed representation and implementation in a KBE platform.

KEYWORDS

Coordinate measuring machine, inspection planning, knowledge based engineering, MOKA.

INTRODUCTION

Manufacturing industry has to face the high competitiveness in a context where whatever contribution to gain more advantage in the market, independently of the level of contribution, demands the exploit of every resource in the company. Today, companies are focusing to intellectual aspects to gain competitive advantage [1-3]. That is, the information era is being exceeded towards the knowledge era, and in that context the development of Knowledge Based Systems (KBS) plays an important role. The companies with higher technological development have invested in the last years significant resources in knowledge-based-technology. Among the key technologies to achieve these objectives one of great importance is the knowledge-based-engineering (KBE). However, the adoption of this technology has been and is still today scarce [1,4].

There are diverse methodologies to capture and represent the knowledge. Most of them are KBS general methodologies which are not particularized to manage the knowledge in engineering. One exception is the MOKA methodology [5], which was developed specifically for the scope of KBE. However, this methodology is focused in the knowledge associated to the product design activity and it does not consider the knowledge associated to the design of the manufacturing and inspection processes. In that context, the inspection process planning with automated machines (e.g. coordinate measuring machines – CMM) offers an application field very interesting for the KBE technologies. The inspection planning requires making decisions about repetitive decisions where explicit knowledge is well understood and, therefore, they are easy to automate. Today these decisions are mainly made by an expert operator.

The life cycle of a system based on knowledge contains several stages. In particular, MOKA proposes six stages (Figure 1): Identify, Justify, Capture, Formalize, Packing and Activation. In reference [5] can be found a more detailed information of these stages. The objective of this paper is based on the Capture activity. This paper deals with the identification of the knowledge required to perform a right inspection planning in a first high-level of approximation, so that it will serve as basis to a following detailed representation and implementation in a KBE platform.

The Identify and Justify activities have not been considered since they refer to the analysis and evaluation of the scope, success and cost of the KBE system. It has already said that the inspection planning with CMM is a good candidate to develop a knowledge based system.

CAPTURE OF ROUGH KNOWLEDGE

Knowledge capitalization is the process of capturing and formalizing expertise before its implementation in a system [6]. This process can be divided in four steps: Knowledge elicitation, Knowledge analysis, Knowledge structuring and Knowledge representation. This paper deals with the Knowledge elicitation, that is, the process of obtaining knowledge from experts. Other authors [7] extend this definition to include elicitation from other sources, such as technical documents, handbooks, illustrations, databases and others. There are many techniques for elicitation, but the most common is to interview to experts. Other common technique is to use data mining techniques to capture knowledge from documents. In that paper, the elicitation has been done only from documents. With that limitation, the only methodology that satisfies this elicitation method is MOKA, since it offers the possibilities of eliciting knowledge from documents within engineering domains through its ontology [6].

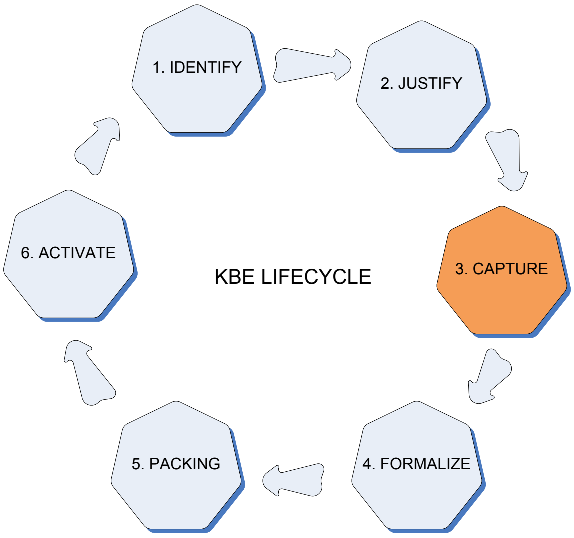

Figure 1: MOKA life cycle.

The MOKA methodology uses five generic types of objects to capture the knowledge in an informal model: Entities, Constraints, Activities, Rules and Illustrations. This objects and their relations constitutes the ontology of MOKA.

- *Entities* describe the elements that describe the product, its structure and features. An entity can be structural, functional or behavioral, depending on the term described.
- *Constraints* describe the limitations of the product or its components and functions.
- *Activities* describe the process, in our case the inspection planning. They contain the strategy and way through the process, the tasks at different levels of decomposition and the inferences.
- *Rules* are associated to activities and actuate as the methods for their realization.
- *Illustrations* represent pass cases, past experiences, additional documents.

Although all of these objects are necessary for the ontology, in our context the main objects are the activities and the rules, since the scope is the design of the process of inspection instead of the design of a product.

Therefore, the first thing to do is to capture the knowledge from the application scope and to convert it to these objects. Following the MOKA methodology, the knowledge has been structured using the ICARE forms. These templates compose the knowledge of the process and represent the minimum content required for the construction of the *Informal Model*.

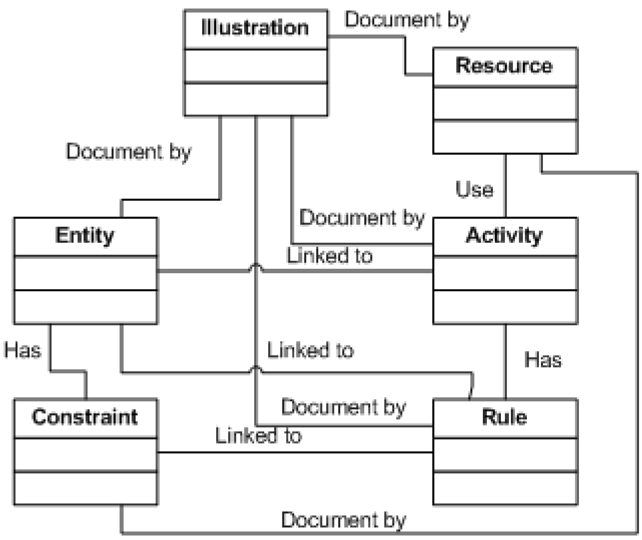

Figure 2. Conceptual model of the ontology used.

Ammar et al [6] proposes an extension to that model in the sense to include two more objects to those proposed by MOKA: *Resource* and *Function*. In the case of the Resource object the reason is to encapsulate the knowledge of the different tools and machines used by manufacturing processes and operations to realize geometries. It is an interesting improvement that fit also adequately to the process of inspection. The importance of this object leads to that it should be considered at the same level as the entity and the activity objects. In the case of the Function object, the reason is to identify the objective of the reasoning activities. We think that this is not necessary since the MOKA ontology already offers ways to consider it, mainly through the Activity and Rule objects. In consequence, in our approximation we have used the MOKA objects plus the Resource object proposed by Ammar et al. The ICARE forms will be then renamed to ICARER. Figure 2 shows this conceptual model.

At this point, the ontology is prepared and the knowledge should be identified and elicited following an extraction strategy. The extraction of knowledge consists in a first approximation in recognizing knowledge objects and their relationships. Among the common methods to transfer the rough knowledge are [5]: a) to build a list of product objects and process objects which will produce the Entity and Activity forms, respectively; b) to begin with the activities, in the case where the process is more important than the product; c) to begin with the entities in the case the product is more important. It is clear that in the case of process planning the most important is the process. Therefore, in our approach we elaborate a list of process objects and we define the activities using IDEF0 diagrams as an aid. The methodology used is gradual in the sense that it obtains first the more general knowledge about the inspection process planning and then the more detailed knowledge to represent it in the form of Informal Model of knowledge.

This procedure corresponds with the CommonKADS views [8] for the Design Process Model (DPM) structured in four layers (Figure 3). In that paper the focus is in the Strategy Layer.

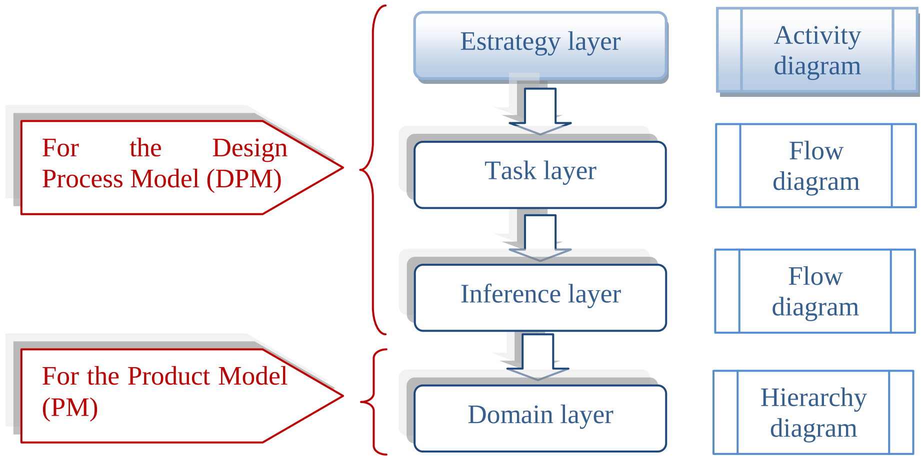

Figure 3: Structured view of CommonKADS.

PREVIOUS ANALYSIS OF THE INFORMATION AND KNOWLEDGE IN THE CMM INSPECTION PLANNING

The objective in the inspection process planning with CMM consists in defining the best sequence of inspection operations, establishing an adequate inspection procedure for each element to inspect. It is necessary knowledge about three areas: a) knowledge about the inspection process, b) knowledge about the resources and c) knowledge about the part or product definition (design) and manufacturing.

The knowledge of the process can be considered as knowledge based on rules or facts which allows defining the basis plans, the process parameters or whatever information related to the inspection plan. The knowledge of resources includes the characteristics of the measurement equipment (probes, scans, etc.), information of fixtures and capacities of equipments in plant. The part definition information contains the necessary data to represent the part, that is, geometry, topology, tolerances, attributes, context dependent features (manufacturing features, inspection features).

In this paper the focus is in the knowledge related to the process. When speaking about the knowledge in automatic inspection process with CMM several aspects should be considered:

- Kind of tolerances to check. It is evident that the complexity for the verification of a linear dimensional tolerance is not the same like the one related to a profile tolerance for a free form surface.
- Accessibility of the elements to inspect. The sensors used in the CMM have a great number of possible orientations. Since every orientation requires a previous calibration, it seems logical to think that the inspection of all of the part elements should be done with the minimum number of orientations. This leads to analyze the accessibility of every element to inspect with the aim to find a valid orientation common for the most of them.

- Number of contact points to acquire. There is not standard which indicates the number of points adequate to inspect an element. The only consideration is the minimum number of points required to reconstruct a geometric element (three points for a plane, two points for a line, and so on). However, this is not an optimum number of points if a precise reconstruction is desired; as far as more points are acquired more precise is the reconstructed geometry, but also the cost of inspection is significantly increased due to the extra time required to perform the inspection. A balanced decision has to be made.
- Distribution of contact points over the elements to inspect. The nature of the inspection process changes when it is done with a pattern or when it is done with a set of points measured over a surface. In the last case two decisions have to be made: where the contact points should be located and how interpret the results derived from them.
- Algorithm to reconstruct the element from the acquired points. Most of the algorithms use the minimum mean-squared root distances between the real point geometry (CMM) and the nominal point geometry (CAD), but there are other algorithms to consider.
- Sensor path without collisions. Several geometrical simplifications can be used for the tool (sensor head, probe and tip) to easily determine if its movement (path) intersects the part or the fixtures geometries.
- Sequencing of operations to optimize the path. The adequate order of operations over the part allows minimizing the changes of orientation for the part and the sensor head, which are a source of error and time consuming.
- Speeds and distances of approaching, retraction and finding for the sensor.

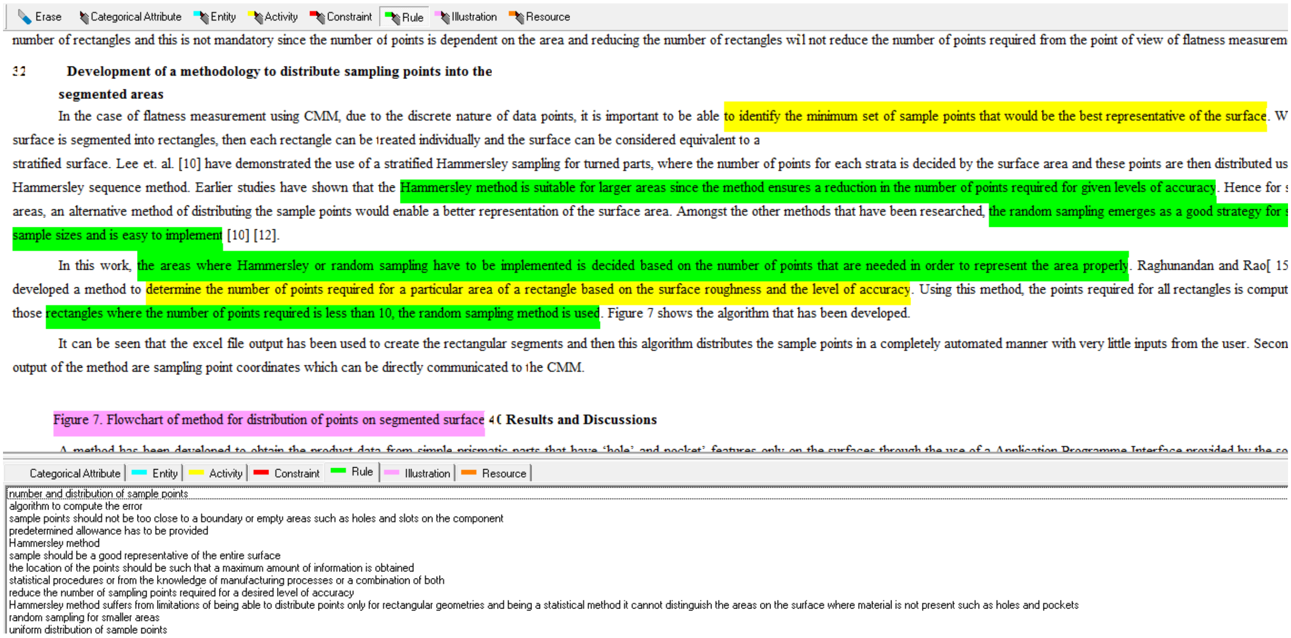

Figure 4. Knowledge elicitation process of objects using a technical document analysis.

IDENTIFICATION OF ACTIVITIES AND ANALYSIS OF THE KNOWLEDGE IN THE CMM INSPECTION PLANNING

The analysis of knowledge is the most difficult step in the capture, since there is no a bidirectional one–to-one correspondence between the expertise information contained in the books, manuals, documents and the items of knowledge [6]. The first task to do is to identify the knowledge components and then the relations among them. The kind of relations is diverse: has rule, linked to, followed by, preceded by, is activated by, is stopped by, is part of, is composed of, and others. Once the items of knowledge and the relationships are identified, the knowledge can be structured.

To identify the objects, basically the activity and rule objects, two complementary actions have been performed. On one hand the reading of a series of documents (papers, reviews, manuals) and the classification of the different terms contained in them into the six categories included in the ontology (Figure 4). On the other hand, a set on IDEF0 diagrams have been developed to describe the activities in the development of inspection planning. These diagrams document the Design Process Model as established in the strategy layer of CommonKADS. Figure 5 shows a small extract of the IDEF diagram corresponding to the activity *Determine contact points*. The detailed definition of each activity and element can be found in reference [9].

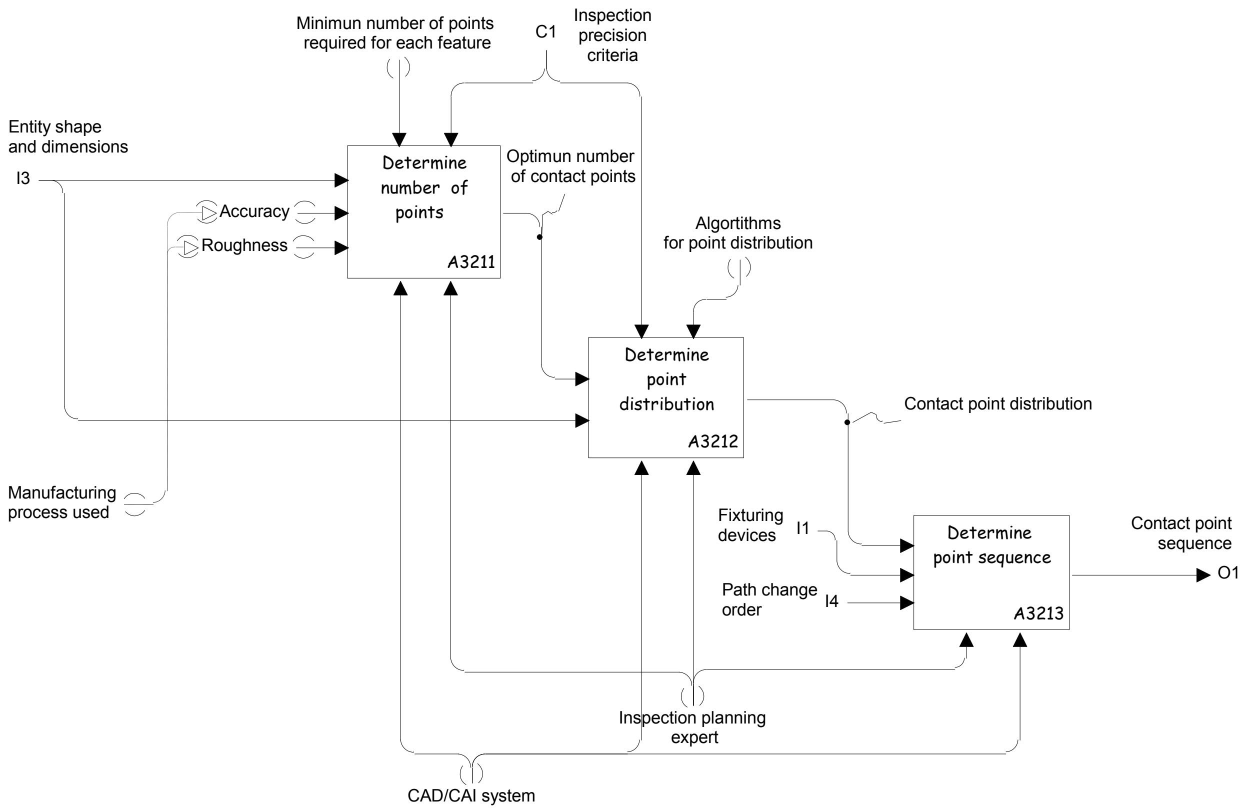

Figure 5. Decomposition of the activity *Determine contact points*.

With these two sources of knowledge, the different objects in the ontology are identified and represented. We have used the PCPACK application for it. This application enables to represent the knowledge with the aid of different diagrams and templates. For example, Figure 6 shows a prototype of activity-rule-constraint-entity diagram for the case of the former activity (*Determine contact points*). The basis of this diagram is the activities identified in the IDEF0 diagrams (yellow boxes), which have been completed with Rules (green diamond boxes – rules are applied to activities); blue boxes correspond to entities and red ovals are constraints that apply to entities and which can be also linked to rules.

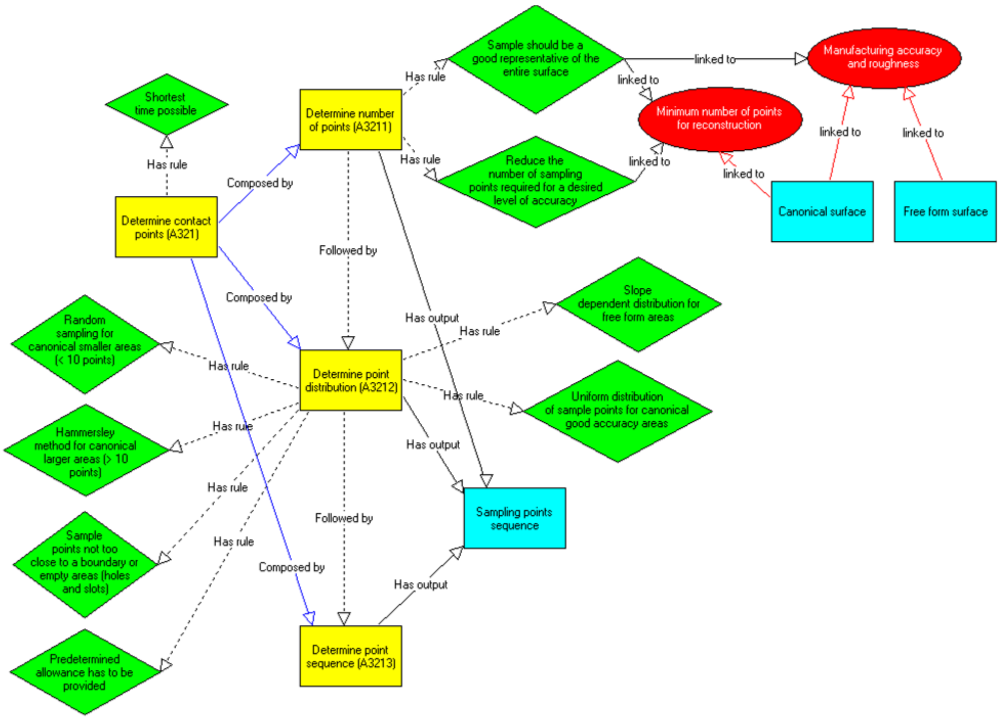

Figure 6: Activity-Rule-Entity-Constraint diagram.

For example, in the case of point distribution determination several rules can be applied depending on the shape of the surface: free form surfaces require a slope dependant point distribution to consider the small radius areas adequately, whereas for canonical surfaces (cylinders, planes, spheres, cones, etc.) a decision can be made to apply a uniform distribution or a random sampling. The random sampling is adequate for small areas (with less than 10 points to acquire) whereas the uniform distribution is adequate for large areas, being a good method the Hammersley distribution.

Another rule to apply is the minimum allowance from the surface boundary, such as the contact point coordinates be not very close to it. Also, contact points should not be located in empty areas like holes or slots which could rest over the surface to inspect. With regard to the previous activity, *Determine number of points*, the general entity *Canonical Surface* is linked to a constraint relative to the minimum number of points for the mathematical reconstruction of a geometry. However, although this constraint establishes a minimum limit for the number of points, the optimum number will depend of the accuracy and roughness provided by the manufacturing process. As it was said before, a balance decision should be made between the time and the accuracy. These two restrictions are linked to the rules attached to the activity *Determine number of points*.

Activity Form	**Determine point distribution (A3212)**	
Name	Determine point distribution (A3212)	
Reference	A3212.Point distribution	
Trigger	Number of points as determined in A3211.Number_of_points	
Input	Number of points; accuracy and roughness of manufactured surface; shape of surface	
Output	Pattern of point distribution; 3D coordinates of contact points	
Potential failure modes	Contact points in empty areas (holes, slots); points near boundaries; narrow access to probe	
Objective	To distribute the contact points for inspection with CMM over a surface.	
Input requer.	Strategy of inspection; standards	
Context	Inspection with CMM and touch trigger probes	
Description	The point distribution should be done to optimize the time and cost for operation while maintaining high level of accuracy. The shape of the area to measure determines the number of points to distribute and the pattern of distribution. Manufacturing processes take influence in the results of distribution.	
Related Activities	**Parent Activity**	Determine contact points (A321)
	Sub Activities	
	Preceding Activities	Determine number of points (A3211)
	Following Activities	Determine point sequence (A3213)
Related Rules	**Rules Involved**	Hammersley method for canonical larger areas (> 10 points), Predetermined allowance has to be provided, Random sampling for canonical smaller areas (< 10 points), Sample points not too close to a boundary or empty areas (holes and slots), Slope dependent distribution for free form areas, Uniform distribution of sample points for canonical good accuracy areas
	Preceding Rules	
	Following Rules	
Entities Involved	Sampling points sequence	
Related Illustrations		
Information Origin	A CAD integrated approach for the distribution of sampling points for flatness inspection using CMM	
To know more	Document about inspection planning review elaborated by J. Barreiro	
Management	**Author**	J. Barreiro
	Date	25/02/2009 - 14:07:43
	Version No	2
	Status	In progress

Figure 7. A-form for the activity *Determine point distribution*.

These diagrams are defined at a high-level of abstraction and should be detailed. However, they allow identifying the main components of knowledge in a first approach.

The next action is to annotate each of the objects in a specific form. This form includes textual detail of the object and the links to other objects. Figure 7 shows an Activity form (A-form) for the commented activity *Determine point distribution*. Some of the fields of the form are mandatory (level 1) and other are optional (level 2 and level 3). For example, fields in level 1 are Name, Reference, Information origin, and management fields such as Name, Date and others. Fields in level 2 are textual and identify the input/output of the activity, the trigger, the objective of the action and its description, the potential modes of failures and the context for information validity. Fields in level 3 are linking references to other activities (parent/child, preceding/following activities), to the rules that applied to the activity or to the entities related to it. Each of these linked elements has its own form (A-form, E-form or R-form). More information about forms can be found in reference [5].

CONCLUSION

Most KBE methodologies have been developed to contain the knowledge about the design problem. Other activities like manufacturing or inspection process design are not in the focus of these methods. However, the MOKA methodology offers the elements and characteristics adequated to extend it to the field of inspection or manufacturing processes. In particular, a mixed ontology between the MOKA and the extended Ammer et al. proposal is considered in that paper. It includes six elements (ICARER): illustration, constraint, activity, rule, entity and resource. This ontology allows managing inspection planning knowledge from different points of views and different forms, integrates it and makes easier the access and mantainment of the relevant information. The IDEF0 diagrams act as a good complement to MOKA forms and diagrams, in particular in the case of the inspection process design model as established in the first layer of CommonKADS and used by MOKA. Although the developments presented are defined at a high-level of abstraction and more work is required in the future, they let to identify in a first step the main aspects of knowledge to consider.

ACKNOWLEDGMENTS

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