Expert System for Implant Material Selection

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***Abstract*— Workflow Management System (WfMS) is a software that enables collaboration of people, processes and monitoring of a defined sequence of tasks, involved in the same business enterprise. There are some WfMSs which enable integration of project activities realized among different institutions. They enable that comprehensive activities carried out at various locations are more easily monitored, with improved internal communication. This paper presents an example of decision support system in Workflow Management System for design, manufacturing and application of customized implants. This support system is based on expert system. Its task is to carry out a selection of biomaterial (or class of material) for a customized implant and then to propose a technological process for implant manufacturing. This model significantly improves the efficiency of WfMS for preoperative planning in medicine.**

***Key words:* Customized implant; Workflow Management System, Expert system.**

I. INTRODUCTION

Technological development has influence to all spheres of the society, especially in the field of information technologies, economy, and the needs of a user. With constant innovation and invention, there are thousands of computer application created every day, on various topics, available worldwide, whose functionality meets the customer needs and market demands. The requirement that the quality low-cost product should be first on the market has led to the formation of multidisciplinary teams of different area experts [1]. On the other hand, Knowledge based technologies have provided the integration of different area knowledge into a single software environment. Such systems are usually based on the application of certain methodologies from the domain of artificial intelligence [2]. The most commonly used are expert systems, genetic algorithms and neural networks. Their application in biomedicine is significant, both in the data monitoring systems, and in advanced decision-making systems.

In comparison to the personalization in industry, personalization in medicine has just recently begun to gain importance. Personalized medicine derives from the belief that same illnesses that afflict different patients cannot be treated in the same manner [3].

An implant is a medical device manufactured to replace a missing biological structure, support a damaged biological structure, or fix an existing biological structure [4]. Implants must respond to specific demands in patient treatment. As such, they are used in almost all the areas and fields of medicine.

Unlike standard implants, which have predetermined geometry and topology, customized implants are completely adjusted to match anatomy and morphology of the selected bone of the specific patient [5]. In this way they fully meet the needs of the patient, thus shortening post-operative treatment period and significantly reducing adverse reactions to the acceptance of implants or possible pain. The patient-specific implant concept is evidenced since 1996, research on implants for hip replacement that is manifested in the need for adaptation and customizing implants [6]; then, since 1998 the first cases about patient-specific implants for skull were developed [7]. These kind of implants are custom devices based on patient-specific requirements [8].

This paper focuses on the presentation of the concept of support expert systems for manufacturing personalized orthopedic implants, more precisely for the selection of implant materials and manufacturing method. Implant material selection using expert system can be made by rankings properties such as strength, formability, corrosion resistance, biocompatibility and small implant price [9]. The application of quantitative decision-making methods for the purpose of biomaterial selection in orthopedic surgery is presented in the paper [10]. A decision support system based on the use of multi-criteria decision making (MCDM) methods, named MCDM Solver, was developed in order to facilitate the selection process of biomedical materials selection and increase confidence and objectivity [11]. Based on these researches, we propose a decision support system in a WfMS.

Bearing in mind that the implants are complex geometric forms, most commonly used method for their design is reverse engineering [12].

In order to manufacture adequate customized implants it is necessary, beside the geometry and topology, to select the appropriate material and manufacturing technology. This process physically takes place partly at clinics (where the process of diagnosing and identifying the problem is performed), then at the implant manufacturing facility the implant is designed and configured (and if possible- manufactured) and finally again at clinics where the implant is embedded. This process requires the knowledge of experts from various fields (doctors, biologists, engineers, etc.). The separation of the processes emphasises the importance of the need for an information system for monitoring action flows within the institutions and mutual communication between them. Such a model is made possible by using the Workflow Management System (WfMS). WfMS is a system that completely defines, manages and executes workflows through the execution of software whose order of execution is driven by a computer representation of the workflow logic [13].

A model of integration technologies for ideation of customized implants [14] work with several interoperability flows, between Bio-CAD, CAD and CAE software, based on requirements. Yang y Cols. [15]

propose integration of technologies as mechanisms to attaching or exchange independent systems that interoperate, and promote results optimization, automation and reduce of process time. Newer researches are based on semantic interoperability for custom orthopedic implants manufacturing [16].

This paper gives the concept of an expert system which is a decision support system to WfMS. The purpose of this system is the selection of materials and the selection of customized implant manufacturing process. Therefore, in the definition of the implant model, the implant knowledge is additionally inserted in the form of facts, which actually forms a knowledge model about the implant. This knowledge, connected by appropriate relations to rule databases for the material selection (or the material class selection), provides the prerequisites for the start of the customized implant production technology selection process.

II. Expert system for implant material selection

The connection between activities which are carried out in the clinics and those which take place in the manufacturing facility is achieved by the workflow management system. The concept of Workflow Management System was successfully tested on WfMS-MD system [17]. In [18], a concept is proposed that integrates all activities for the design and manufacturing of customized implants. This concept implies the integration of the processes in orthopaedic clinics and manufacturing facilities by using the information system which would manage the whole process, starting from the doctor's diagnosis and ending with the manufacturing of the implant which is adjusted to a specific patient. . This system provides flexibility of the process of selecting and embedding implants and is realized through cooperation with the manufacturing of customized implants, on one side, and through the possibility to respond to exceptions which may occur during the process, on the other.

The process of designing and manufacturing customized implants [19] may be physically realized by defining activities which would be monitored by WfMS. The process diagram realized [20] is shown in Fig. 1.

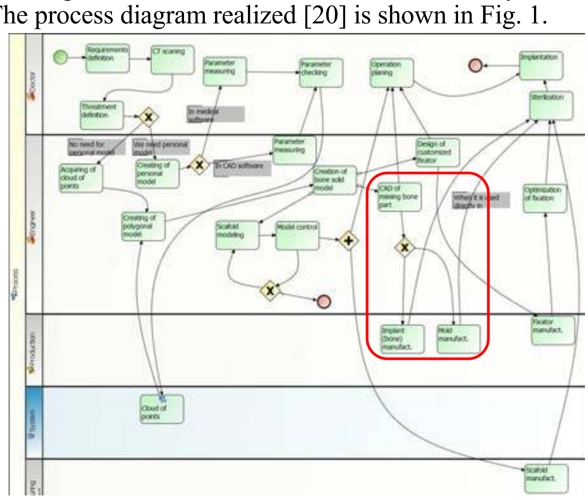

Figure 1. The process of creating customized osteofixation material.

The presented system is extensive and monitors the complete integration process, from defining requirements, CT / MRI scans (doctor's task), then the process of reverse engineering to obtain a complete 3D CAD model of bone missing part (engineer's task) in order for an implant to be manufactured, and then sterilized immediately prior to embedding. The system is connected to decision support system based on the use of expert systems, which should help in the decision making process necessary to produce a customized implant. It incorporates the knowledge (in the form of rules) of an expert who is not even a part of the team producing implants.

Expert systems are meant to solve real complex problems by reasoning about knowledge which normally would require a specialized human expert (such as a doctor). The typical structure of an expert system is shown in Figure 2 and is made of: a knowledge base, an inference engine, and an interface.

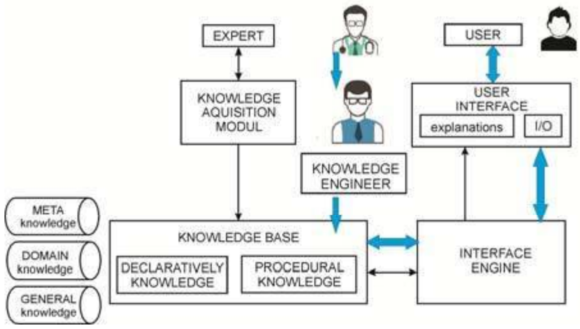

Figure 2. Architecture of expert system.

Since in the expert system the decision making process and knowledge base are separated, parts of knowledge within the knowledge base can be easily supplemented or modified. Knowledge base contains certain rules, which describe the knowledge and work logic of a particular field expert, in this case of a technologist.

The task of the expert system designed in this paper is to recommend a suitable material to meet the requirements of a customized implant, and then to decide on the selection of the manufacturing technological process.

Integration between expert systems and WfMS is performed by means of rule-based Web application. This Web application receives input parameters from the user through the user interface. Input parameters are, in our case, represented in the customized implant knowledge model. In this way the values of characteristics that describe the implant are defined.

Figure 3. Architecture of Web rule-based application.

The role of a Web browser is to process and forward the parameters to the application on a server by using the appropriate web application. Web application itself is implemented using JavaEE technologies and represents the part of the WfMS system as shown in Figure 3. WfMS system receives parameters, processes them further, and then forwards them to the expert system comprising a knowledge base, i.e. rules. This expert system is actually a rule-based application implemented by Jess rule engine [21].

III. IMPLANT KNOWLEDGE MODEL

The basic building block of every expert system is knowledge. Knowledge in expert system consists of facts and heuristics. While heuristics is made of rules of judgment based on experience or intuition (tacit knowledge domain), the facts are widely distributed, publicly available information that were agreed on at the expert level in subject areas (explicit knowledge domain). For successful work of our expert system it is necessary that there is an adequate knowledge transfer (Figure 4) from the certain field expert to knowledge engineer, in order for an engineer to adequately present accumulated knowledge in the knowledge base.

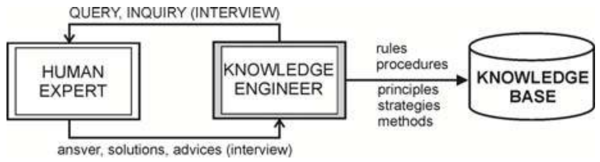

Figure 4. Knowledge transfer from an expert to an expert system knowledge base.

In order for a resulting database of expert knowledge to have its function, it needs to connect on one side to the specific problem database (in our case it is the knowledge model about customized implant), and on the other, with reasoning mechanisms (which is part of the expert shell). The following table gives a part of the knowledge base about customized implants. This knowledge base is adequately filled by orthopaedist and engineers who designed and manufactured the implant. Since these parameters are essential, it is important to present a knowledge model about customized implant with the facts, characteristics, as well as with the description of the facts or by defining certain parameters values.

TABLE I.
CUSTOMIZED IMPLANT MODEL KNOWLEDGE

Parameter	Fact
Gender	Male
Age	30 – 49
Diagnosis	Fracture
Bone	Tibia
Location	Diaphyseal
AO/OTA Classification of fracture	42-B2
Implant type	Internal
Implant kind	Plate
Implant volume	10-15 cm^3
Weight	Low – Medium
Number of necessary joints – screw	8
Number of necessary joints – K wire	2
Biocompatibility	Very high
Sterilizability	Very high
Endurance Limit	High
Lifetime	Max

Since the expert system is connected to WfMS, it is important that they are designed with the same technology and programming languages in order to ensure compatibility. WfMS MD uses a modified open source system Enhydra Shark as workflow engine. Enhydra Shark is a flexible and extendable workflow management facility compliant, embeddable or standalone Java workflow engine. For execution of the rules, we use the expert shell JESS, a rule engine and scripting environment written entirely in the Java language.

IV. REVIEW OF A PART OF BIOMATERIAL CLASS KNOWLEDGE BASE AND AN EXAMPLE OF DECISION-MAKING PROCESS

As there is no universal or optimal material, whose characteristics fit each implant model, it is necessary from a large number of available biomaterials to choose the one that, according to certain specific requirements, fully corresponds to the model.

On the other hand, a wide range of materials ensures that several types of materials belonging to different classes of biomaterials will have certain properties. In order to make a decision on the selection of the concrete material, it is often necessary to predict the resolution of a conflict that will clearly define the procedure for determining priorities, thus the process of material selection in fully defined.

The structure of a thus designed expert system consists of 3 modules: a module for material class selection, a module for material type selection, and a module for customized implant manufacturing technology selection. A model of a part of the expert system for biomaterial class selection is shown in Figure 5.

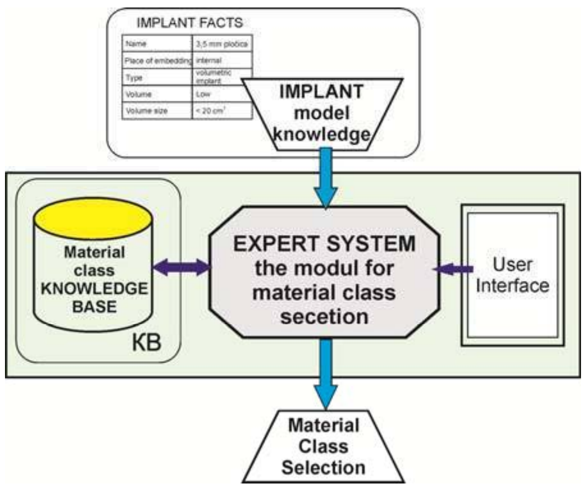

Figure 5. Model of a part of the designed expert system.

Based on the recognized class of materials, by further use the new module of the expert system, we can achieve the selection of specific material for implant manufacturing. Through the latest module of a designed expert system, the customized implant manufacturing technology is determined, according to available resources and applicable technologies.

In Table II there are some of the rules about material classes. For defined parameters in the form of facts, there are three classes of biomaterials presented and their comparison in the certain value range.

After integrating the knowledge about the model, and the biomaterial classes and other necessary knowledge models, in the expert system, an opportunity is created that a user of such a proposed system, e.g. a doctor, can select material (class) for the customized implants.

TABLE II.
RULE BASE ON MATERIAL CLASSES (EXTRACT)

	Tensile modulus	Yield strength	Ultimate strength	Strain to failure	Ductility	Toughness	Resistance to *in vivo* attack	Local host response (bulk)	implant manufacturing location
Metals	M	H	H	M	M	H	L	H	O
Ceramics	H	/	M	L	L	M	H	L	I/O
Polymers	L	L	L	H	H	L	M	M	O
explanations									
L- Lowest; M- Intermediate; H- Highest;					O – Out I – In I/O – In and Out				

By inserting this knowledge in JESS a code is in the following form:

```
;(watch all)
(reset)
(deftemplate feature_has_value (slot feature)
(slot value))

(defrule choose_P
    (and ... )

(defrule choose_C
    (and ... )

(defrule choose_M
    (and
          (or (not (feature_has_value (feature
TM))) (feature_has_value (feature TM) (value
L)))
          (or (not (feature_has_value (feature
YS))) (feature_has_value (feature YS) (value
L)))
          (or (not (feature_has_value (feature
US))) (feature_has_value (feature US) (value
L)))
          (or (not (feature_has_value (feature
SF))) (feature_has_value (feature SF) (value
H)))
          (or (not (feature_has_value (feature
DT))) (feature_has_value (feature DT) (value
H)))
          (or (not (feature_has_value (feature
UT))) (feature_has_value (feature UT) (value
L)))
          (or (not (feature_has_value (feature
HRC))) (feature_has_value (feature HRC) (value
L)))
          (or (not (feature_has_value (feature
D))) (feature_has_value (feature D) (value L)))
          (or (not (feature_has_value (feature
R))) (feature_has_value (feature R) (value M)))
          (or (not (feature_has_value (feature
LHR))) (feature_has_value (feature LHR) (value
M)))
          (or (not (feature_has_value (feature
M))) (feature_has_value (feature M) (value L)))
          (or (not (feature_has_value (feature
PP))) (feature_has_value (feature PP) (value
P)))
          (or (not (feature_has_value (feature
W))) (feature_has_value (feature W) (value L)))
          )
    => (printout t "Choose Metal" crlf))
```

```
(bind ?another y)
(while (= ?another y)
               (printout t "Type the feature?")
               (bind ?f (read))
               (printout t "Type the value?")
               (bind ?v (read))
       (assert (feature_has_value (feature ?f)
(value ?v)))

(bind ?another (read)))

(run)
```

As a result Jess has, based on the criteria given by user and the defined rule base, selected the biomaterial class. In this scenario the suggested solution is the metallic biomaterial (Figure 6).

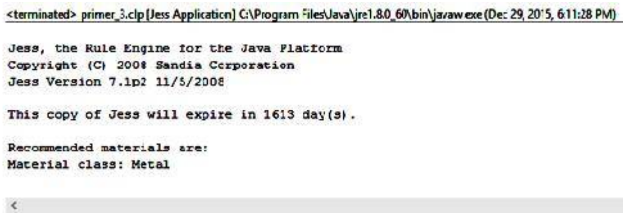

Figure 6. Biomaterial class recommended by Jess

Biomaterial class recommended by Jess (Fig. 6) is further presented to the user through Web interface.

V. CONCLUSION

Integration of business systems that take place in different institutions and in different locations is successfully implemented through the use of information technologies and Workflow Management System. Comprehensiveness and massiveness of WfMS in a certain part requires the use of other technologies, and in this way, the system can be upgraded.

Web based application connects expert system with WfMS. Thus, the business system is upgraded with the appropriate decision support system.

The proposed model concept has been successfully verified by selecting the appropriate class of biomaterials for the purposes of customized implant manufacturing.

Future research will focus on the development of the concept of expert system for customized implant manufacturability analysis, as well as on the development of expert system modules for the selection of materials and manufacturing process.

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