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A. STAWOWY*, A. MACIOŁ*, R. WRONA**

CASTING PROCESS SELECTION USING BUSINESS RULES APPROACH

ZASTOSOWANIE BUSINESS RULES DO DOBORU TECHNOLOGII WYKONANIA ODLEWÓW

This paper presents the application of business rules idea for the selection of casting process taking into account the economic and technological requirements. Business Rules Management (BRM) systems allow non-technical business people to change the rules, analyze them for errors, and test and simulate them for impact analysis. Although BRM is focused on business processes improvement, it is possible to use this approach in technology management. The model of technology selection problem, the knowledge base as a set of rules and the solutions of exemplar cases are presented in the paper.

The results indicate that the proposed business rules tool is feasible as a complete knowledge base and technology management method.

Keywords: Casting selection, Application of Information Technology to the Foundry Industry, Artificial Intelligence

W pracy przedstawiono sposób rozwiązywania problemu doboru technologii wykonania odlewu przy użyciu koncepcji reguł biznesowych (BRM - Business Rules Management). Systemy BRM pozwalają użytkownikowi-menedżerowi, który nie jest programistą, formułować, aktualizować weryfikować i symulować reguły w sposób zbliżony do języka naturalnego. Aczkolwiek BRM jest ukierunkowana na poprawę procesów biznesowych, z powodzeniem można stosować tę koncepcję w zarządzaniu technologią. Przedstawiony został model problemu decyzyjnego doboru technologii, zestaw reguł służących do jego rozwiązania oraz przykłady rozwiązania konkretnych zadań.

Uzyskane wyniki dowiodły możliwości zapisu wiedzy i wsparcia zarządzania technologią z wykorzystaniem nowoczesnych koncepcji zarządzania i informatyki.

1. Introduction

One of the main stages of the production process design is adequate technology selection. Designing casting process requires extensive knowledge of various casting techniques including their capabilities and limitations. This decision process should take into account the casting material, weight, dimensions, batch size, thickness of a casting wall, acceptance specifications. Apart from these, processes are limited by other constraints like the range of weights, economical quantity and shape complexity. The decisions of selecting the manufacturing process for the given product may be automated or supported by some artificial intelligence tools [2, 3, 11]. These systems help the designer in identifying alternatives early in the design process.

In the paper we present the Business Rules Engine (BRE) for the selection of casting processes. This is one of the possible implementations of the BRE tool, developed as the project cofounded by the European Union. The engine operates in accordance with general BRM idea and simultaneously includes specific technological knowledge.

Research data reveal that typical decision problems connected with technology issues do not require preparation of complex knowledge models. Nevertheless, the number of rules may in some cases grow to hundreds and complicate the acquisition of knowledge, at the same time raising the requirements above the limits settled by inference systems.

There is number of literature sources that report applicability of expert systems for support of technological decisions. However, those should be treated as incidental appearances. Despite various range of their applicability, they are characterized by an invariable, a priori defined structure. There is a shortage of solutions that would allow a user a simple and functional extension of knowledge base as well as introduction of her/his own research results.

* FACULTY OF MANAGEMENT, AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, 30-067 KRAKÓW, UL. GRAMATYKA 10, POLAND
** FACULTY OF FOUNDRY ENGINEERING, AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, 30-059 KRAKÓW, UL. REYMONTA 23, POLAND

It leads to a major decrease in flexibility of such system as well as probable premature aging of knowledge, which eventually forces frequent changes of the system. As a result, such systems can be neither improved by the users on their own nor with slight help from IT specialists, even though such flexibility of BRM solutions was the main contribution to their popularity. The purpose of our research and development works is identification of BRM conception such that solutions being characterized by all the advantages of these tools could be applied in the technological field.

2. Business Rules concept

Business Rules Management is one of the latest approaches to computer support of business activities: BRM concept is implemented in business practice as Business Rules Management Systems (BRMS). The Business Rules (BR) approach is defined as a formal way of managing and automating an organization's business rules so that the business behaves and evolves as its leaders intend [4, 12].

2.1. BR as a business asset

The commonly accepted description of rules concept is The Business Rules Manifesto [13], stating that:

– rules are essential for business models, business rules are a vital business asset,
– rules are explicit constraints on behavior, not process or procedures,
– rules should be expressed declaratively in natural-language sentences for the business audience,
– rules should originate from knowledgeable business people,
– business people should have tools available to help them formulate, validate, and manage rules.

2.2. Knowledge representation

The Business Rules approach requires a source rule repository which is a form of a knowledge base. The knowledge base has a hierarchical structure and – at the first level – consists of rule sets; a rule set is a group of coherent rules. The further hierarchy levels are as follows:

– rule consists of atoms e.g. *IF machine has weak effectiveness THEN machine is to-be-replaced*,
– single atom consists of terms e.g. *machine has poor effectiveness*,
– term is a word or expression that has a precisely limited meaning in a given knowledge base e.g. *machine, poor effectiveness, to-be-replaced.*

The business knowledge can be represented in various forms as decision tables, decision trees, decision grids, and in the textual form [12].

2.3. Business Rule Management Systems

A Business Rule Management System is a computer system used to define, distribute, execute, monitor and maintain the decision logic. The major objective of BRMS is to allow describing business and technological processes to be implemented independently of the software system.

A BRMS typically consist of:

– rules repository, which allows decision logic to be externalized from core application code,
– tools to define and manage rules repository by both IT staff and business analysts,
– a runtime environment, allowing applications to fire decision logic and execute it using a business rules engine.

The key benefits of a BRMS include [6]:

– reduce time and resources required to deploy changes,
– author and maintain rules using non-technical language so business experts can manage and validate decision logic with a little, if any, help from IT staff,
– increased control over implemented decision logic for better guide and control the business,
– the ability to express decision logic with increased precision, using a business vocabulary syntax and graphical rule representations,
– improved processes efficiency through increased decision automation.

2.4. BRMS applications

Rule-based decision tools can be used for quantitative as well as qualitative decisions. Situations in which knowledge-based systems have proved useful include:

– CRM systems (rules describes e.g. an individual client's profile),
– customer assessment systems (e.g. credit rating, customer value),
– sales systems (e.g. complex price lists and cross-selling offers),
– systems supporting supply chain management (e.g. supplier selection),
– cost control and budgeting (e.g. cost accounting, cost estimation, budgeting rules),
– production management (e.g. scheduling, machine maintenance, fault diagnosis, inventory management),
– energy management (power distribution networks, power plant management).

3. Related research

In the field of automatic casting process selection and related problems, the literature is not extensive. Darwish and Tamini [2] proposed a casting process selection expert system. Based on required casting characteristics, the system produces a list of candidate process(es) to manufacture a particular part. The expert system may be used either by those with much experience of designing casting to save their valuable time, or beginners who need a lot of guidance. Mantipragada et al. [9] proposed a feature-based approach to model sheet-metal part during the design process. Features allow a structured representation of knowledge about tooling and process conditions in a common scheme. The authors proposed the computer system that integrates the analysis modules, CAD, and a knowledge-based system to check sheet metal formability. Mookherjee and Bhattacharyya [10] introduced Extool, an expert system to automatically select the appropriate turning tools or milling insert, the material and the geometry. Extool uses a relational database as the knowledge base to store data for the turning and the milling operations, and for other related activities (tool geometry, trouble shooting, chip-breaker designing, suggestions for proper use of the tool, etc.). In the other study, Yue et al. [14] discussed the CAD/CAE/CAM integrated system to aid die casting of sedan parts. Their expert system tool is built to design the technological scheme of die casting process: the parameters such as the injection pressure, plunger speed, gate velocity and filling time, etc. are selected and checked depending on the type of alloy, and the wall thickness and structure of the casting. Zhang et al. [15] presented the prototype of the web-based forging design system. The system incorporates a finite element simulation module and an expert system in an intelligent knowledge-based system framework. The product information model is described in XML which simplifies information exchange through the web. Kumar and Singh [7] developed an intelligent die-set selection system (IDSS) using production rule based expert system approach for supporting die designers for selection of the die-set of press tool. The system comprises more than 80 *If* ... *Then* production rules. IDSS makes use of the forward chaining for searching a solution to a particular problem. During a consultation, the user loads the system into the prompt area of AutoCAD. The system output includes recommendations on the optimal selection of the die-set with appropriate dimensions for the given sheet metal operation. Cakir et al. [1] designed DieEX to give optimum solutions in selecting the tool type, workholding method, machining method, feed direction and machining tolerances as well as to give useful practical recommendations about the rules of entrance. The knowledge contained in a relational database is compiled from three main sources: from human experts working in the field of die and mold making, from human experts dealing with CAD/CAM applications and from the technical documents, catalogues or handbooks of various cutting tool producing companies. Ravi and Akarte [11] proposed a virtual foundry environment for preliminary process planning of cast elements. The plans are automatically generated by case based reasoning using the nearest neighbour algorithm. The database contains the castings descriptions created using Casting Data Markup Language. More recently, Maciol et al. [8] presented the model of a decision problem and rule-based expert system for the selection of casting process. The shell system was used to prototype the concept.

4. Description of proposed method

The sources of knowledge about the foundry technology are technical standards, monographs and handbooks. The knowledge is presented in the form of tables interrelating various pieces of information about the respective technologies and parameters of the ready products, possible to obtain when these products are made by a selected technology. The set of technical parameters depends on the type of casting and covers the following properties:

1. product attributes (material, weight, thickness, shape),
2. production attributes (volume and rate),
3. manufacturing attributes (surface quality, dimensional accuracy, roughness, porosity),
4. trading attributes (costs, economic lot size).

The inference consists in finding out (by searching in tables comprising various technical parameters) a set of technologies possible for use in a given case, selecting next from this set the technology which is thought to be the best and most effective in realization of a specific product. The technological processes written down in the knowledge base include: casting in sand moulds, die casting, shell casting, continuous casting, investment process, and centrifugal casting. The summary of considered processes (based on [2]) is given in Tables 1 and 2.

TABLE 1

The core characteristics of casting processes

Method	Range of metals	Tolerances [cm/cm]	Mass range	Minimum thickness [mm]	Surface roughness [µm]
Sand casting	no limit	0.03-0.05	up to 30 Mg	2.5	5-25
Die casting	non-ferrous	0.015-0.03	up to 50 kg	0.5	1-2
Shell mold	no limit	0.02-0.05	up to 20 kg	1.0	2-5
Continuous	no limit	0.01-0.025	up to 50 kg	3.0	2-3
Investment	no limit	0.003-0.005	up to 10 kg	0.5	1.5-2
Centrifugal	no limit	0.03-0.1	up to 10 Mg	6.0	5-25

TABLE 2

Scoring of various casting processes (scale 1-7, 1 – the best)

Method/ property	Sand casting	Die casting	Shell mold	Continuous	Investment	Centrifugal
Porosity	7	5-3	3-2	3-4	2-1	1-2
Surface quality	6-7	2-1	3-4	4-5	1	5-4
Dimensional accuracy	6-7	1-2	4-3	5-4	3-2	5-4
Strength	7-5	1-2	3-2	4	7-5	3
Mold cost	1-2	6-7	2	5	4	3
Production rate: – small lot size – large lot size	 2 3	 6-7 1-2	 1 2	 4 3	 3 5	 5 4
Minimum thickness	4	2-3	2-1	5	1	6-7
Economic lot size	up to mass production	min. 1000	min. 100	min. 1000	100-5000	200-850

Darwish i Tamimi [2] in their expert system proposed the attributes coding as categorical instead of continuous variable (e.g. 4 weight classes). We decided to use the same approach but only for the attributes which strongly differentiate the casting processes. These parameters are: dimensional tolerance, strength and surface roughness (see Table 3). By using categorical values the casting processes can be characterized as it is shown in Table 4.

TABLE 3

Tolerance, strength and roughness classes

Tolerances [cm/cm]	<0.01	0.01-0.03	>0.03	
class	low	moderate	high	
Strength [MPa]	<400	400-500	>500	
class	low	moderate	high	
Roughness [µm]	1-2	2-3	3-5	>5
class	RG1	RG2	RG3	RG4

TABLE 4

Values of category parameters describing casting processes

Method/property	Tolerance	Strength	Roughness
Sand casting	high	high	RG4
Die casting	moderate	low	RG1
Shell mold	moderate, high	moderate	RG2, RG3
Continuous	moderate	moderate	RG2
Investment	low	high	RG1
Centrifugal	high	moderate	RG4

Only two combinations of categorical parameters are the same: one from four shell mold processes and continuous casting (*moderate, moderate, RG2* for tolerance, strength and roughness, respectively), but the continuous variables identify these processes unambiguously. Finally, we obtained the knowledge set presented in Table 5a and Table 5b.

TABLE 5a

A revised characteristic of casting processes – part 1

Method	Tolerance	Strength	Roughness	Range of metals	Mass range
Sand casting	high	high	RG4	no limit	up to 30 Mg
Die casting	moderate	low	RG1	non-ferrous	up to 50 kg
Shell mold 1	moderate	moderate	RG2	no limit	up to 20 kg
Shell mold 2	moderate	moderate	RG3	no limit	up to 20 kg
Shell mold 3	high	moderate	RG2	no limit	up to 20 kg
Shell mold 4	high	moderate	RG3	no limit	up to 20 kg
Continuous	moderate	moderate	RG2	no limit	up to 50 kg
Investment	low	high	RG1	no limit	up to 10 kg
Centrifugal	high	moderate	RG4	no limit	up to 10 Mg

TABLE 5b

A revised characteristic of casting processes – part 2

Method	Minimum thickness [mm]	Economic lot size	Production rate for small lot size	Production rate for large lot size
Sand casting	2.5	>=1	high	moderate
Die casting	0.5	>=1000	low	high
Shell mold 1	1.0	>= 100	high	high
Shell mold 2	1.0	>= 100	high	high
Shell mold 3	1.0	>= 100	high	high
Shell mold 4	1.0	>= 100	high	high
Continuous	3.0	>= 1000	moderate	moderate
Investment	0.5	100-5000	moderate	moderate
Centrifugal	6.0	200-850	moderate	moderate

Thirteen variables are used to create 44 rules on the basis of the above attributes. The variables are defined in Table 6 and the rules are listed in Table 7. The *source* category of variables means variables inputted by user, *intermediate* – calculated during rules execution, *final* – outputted by system. In our rule engine the rules are written in **If . . . Then** form (without **Else** part) and a single rule may contain maximum 4 premises.

TABLE 6

The set of variables used in final rules set

Id	Variable Name	Type	Description	Category
1	Metal	Enum	Range of metals	source
2	Thickness	Real	Product thickness [mm]	source
3	Weight	Real	Product weight [kg]	source
4	ProdVolume	Real	Production volume [items]	source
5	ProdRate	Enum	Production rate [items/h]	source
6	Roughness	Real	Allowable product roughness [µm]	source
7	Tolerance	Real	Allowable dimensional tolerance of product [cm/cm]	source
8	Strength	Real	Minimal product strength [MPa]	source
9	LimSeria	Real	Limit of mass production [items]	source
10	ToleranceGroup	Enum	Group of dimensional tolerance	intermediate
11	StrengthGroup	Enum	Group of product strength	intermediate
12	RoughnessGroup	Enum	Group of product roughness	intermediate
13	PrefTechn	Text	Preferred casting process	final

TABLE 7

The set of rules used to solve the selection of the casting processes problem

Id	Premises and conclusion
1	**If** Tolerance<0.01 **Then** ToleranceGroup:=“low”
2	**If** Tolerance>=0.01 **And** Tolerance<0.03 **Then** ToleranceGroup:=“moderate”
3	**If** Tolerance>=0.03 **Then** ToleranceGroup:=“high”
4	**If** Strength<300 **Then** StrengthGroup:=“low”
5	**If** Strength>=300 **And** Strength<500 **Then** StrengthGroup:=“moderate”
6	**If** Strength>=500 **Then** StrengthGroup:=“high”
7	**If** Roughness<=2 **Then** RoughnessGroup:=“RG1”
8	**If** Roughness>2 **And** Roughness<=3 **Then** RoughnessGroup:=“RG2”
9	**If** Roughness>3 **And** Roughness<=5 **Then** RoughnessGroup:=“RG3”
10	**If** Roughness>5 **Then** RoughnessGroup:=“RG4”
11	**If** ProdVolume>0 **Then** LimSeria:=1500
12	**If** ProdVolume>=0 **Then** PrefTechn:=“absent”
13	**If** ToleranceGroup=“high” **And** StrengthGroup=“high” **And** RoughnessGroup=“RG4” **And** Thickness>=2.5 **Then** PrefTechn:=“T1”
14	**If** ToleranceGroup=“moderate” **And** StrengthGroup=“low” **And** RoughnessGroup=“RG1” **And** Thickness>=0.5 **Then** PrefTechn:=“T2”
15	**If** ToleranceGroup=“moderate” **And** StrengthGroup=“moderate” **And** RoughnessGroup=“RG2” **And** Thickness>=1.0 **Then** PrefTechn:=“T31”
16	**If** ToleranceGroup=“moderate” **And** StrengthGroup=“moderate” **And** RoughnessGroup=“RG3” **And** Thickness>=1.0 **Then** PrefTechn:=“T32”
17	**If** ToleranceGroup=“high” **And** StrengthGroup=“moderate” **And** RoughnessGroup=“RG2” **And** Thickness>=1.0 **Then** PrefTechn:=“T33”
18	**If** ToleranceGroup=“high” **And** StrengthGroup=“moderate” **And** RoughnessGroup=“RG3” **And** Thickness>=1.0 **Then** PrefTechn:=“T34”
19	**If** ToleranceGroup=“moderate” **And** StrengthGroup=“moderate” **And** RoughnessGroup=“RG2” **And** Thickness>=3.0 **Then** PrefTechn:=“T4”
20	**If** ToleranceGroup=“moderate” **And** StrengthGroup=“moderate” **And** RoughnessGroup=“RG2” **And** Thickness>=3.0 **Then** PrefTechn2:=“T31”
21	**If** ToleranceGroup=“low” **And** StrengthGroup=“high” **And** RoughnessGroup=“RG1” **And** Thickness>=0.5 **Then** PrefTechn:=“T5”
22	**If** ToleranceGroup=“high” **And** StrengthGroup=“moderate” **And** RoughnessGroup=“RG4” **And** Thickness>=6.0 **Then** PrefTechn:=“T6”
23	**If** PrefTechn=“T1” **And** ProdVolume<LimSeria **And** ProdRate=“high” **Then** PrefTechn:=“sand casting”
24	**If** PrefTechn=“T1” **And** ProdVolume>=LimSeria **And** ProdRate=“moderate” **Then** PrefTechn:=“sand casting”
25	**If** PrefTechn=“T2” **And** Metal=“non-ferrous” **And** Weight<=50 **Then** PrefTechn:=“TN”
26	**If** PrefTechn=“TN” **And** ProdVolume<1000 **Then** PrefTechn:=“absent”
27	**If** PrefTechn=“TN” **And** ProdVolume>=1000 **And** ProdVolume<LimSeria **And** ProdRate=“low” **Then** PrefTechn:=“die casting”
28	**If** PrefTechn=“TN” **And** ProdVolume>=1000 **And** ProdVolume>=LimSeria **And** ProdRate=“high” **Then** PrefTechn:=“die casting”
29	**If** PrefTechn=“T32” **And** Weight<=20 **Then** PrefTechn:=“TN”
30	**If** PrefTechn=“TN” **And** ProdVolume>=100 **And** ProdRate=“high” **Then** PrefTechn:=“shell casting”
31	**If** PrefTechn=“T33” **And** Weight<=20 **Then** PrefTechn:=“TN”
32	**If** PrefTechn=“TN” **And** ProdVolume>=100 **And** ProdRate=“high” **Then** PrefTechn:=“shell casting”
33	**If** PrefTechn=“T34” **And** Weight<=20 **Then** PrefTechn:=“TN”
34	**If** PrefTechn=“TN” **And** ProdVolume>=100 **And** ProdRate=“high” **Then** PrefTechn:=“shell casting”
35	**If** PrefTechn=“T31” **And** Weight<=20 **Then** PrefTechn:=“TN”
36	**If** PrefTechn=“TN” **And** ProdVolume>=100 **And** ProdRate=“high” **Then** PrefTechn:=“shell casting”
37	**If** PrefTechn=“T4” **And** Weight<=50 **Then** PrefTechn:=“TN”
38	**If** PrefTechn=“TN” **And** ProdVolume>=1000 **And** ProdRate=“moderate” **Then** PrefTechn:=“continuous casting”
39	**If** PrefTechn=“T5” **And** Weight<=10 **Then** PrefTechn:=“TN”
40	**If** PrefTechn=“TN” **And** ProdVolume>=100 **And** ProdVolume<5000 **And** ProdRate=“moderate” **Then** PrefTechn:=“investment process”
41	**If** PrefTechn=“T6” **And** Weight<=10000 **Then** PrefTechn:=“TN”
42	**If** PrefTechn=“TN” **And** ProdVolume>=200 **And** ProdVolume<850 **And** ProdRate=“moderate” **Then** PrefTechn:=“centrifugal casting”
43	**If** Length(PrefTechn)>6 **Then** Output(“The recommended process is ”&PrefTechn)
44	**If** Length(PrefTechn)<=6 **Then** Output(“There is no process that meets your requirements”)

Remarks:

1. In our rules engine is possible to handle variables and matrixes, but the values are used to clarify the rules meaning (e.g. rules 1 to 10).
2. The rule is the only way to assign a value to a variable, as it is shown in rules no. 11 and 12.
3. The rule may contain built-in functions e.g. *Length* (gives string length) or *Output* (prints string on a screen), as it is shown in rules no. 43 and 44.

In order to test the performance of our business rules system we considered 5 cases which are described in more detail in Table 8. It can be observed that the proposed rules set becomes a complete and coherent knowledge repository which allows for drawing unambiguous conclusions.

TABLE 8

Test cases with results and explanations

No.	Parameter	Value	Conclusion / explanation
1	Metal	ferrous	**There is no process that meets the requirements** It is not possible to manufacture a product with thickness less than 0.5 mm.
	Thickness	0.3	
	Weight	67	
	ProdVolume	1600	
	ProdRate	moderate	
	Roughness	2.5	
	Tolerance	0.02	
	MinStrength	450	
2	Metal	ferrous	**Continuous casting** Only this process meets all requirements
	Thickness	3.5	
	Weight	37	
	ProdVolume	1600	
	ProdRate	moderate	
	Roughness	2.5	
	Tolerance	0.02	
	MinStrength	450	
3	Metal	ferrous	**Shell mold casting** Only this process meets all requirements.
	Thickness	3.5	
	Weight	57	
	ProdVolume	600	
	ProdRate	high	
	Roughness	6.5	
	Tolerance	0.04	
	MinStrength	510	
4	Metal	Al	**Continuous casting** Only this process meets all requirements.
	Thickness	1.5	
	Weight	1600	
	ProdVolume	1200	
	ProdRate	low	
	Roughness	1.5	
	Tolerance	0.025	
	MinStrength	375	
5	Metal	ferrous	**Shell mold casting** Physical parameters permit shell mold or continuous casting, but “high” production rate is possible to obtain only with shell mold casting.
	Thickness	3.7	
	Weight	45	
	ProdVolume	900	
	ProdRate	high	
	Roughness	2.5	
	Tolerance	0.025	
	MinStrength	475	

5. Conclusions

Business rules can successfully support a wide range of technology and management decisions, starting from sales management and marketing activities, through product design and configuration, to production planning and scheduling. Knowledge bases utilizing business rules approach combined with modern architecture of computer systems allow for decision making in various business and technology activities, product and technology design among them.

The aim of this paper was to present a possible application of a rule-based approach in technology selection. The proposed engine operates in accordance with general BRM idea but at the same time includes specific technological knowledge. The system may help the designer in identifying alternatives early in the design process.

The problem under investigation appeared to be not very complicated and declarative knowledge proved sufficient to solve it. The general answer to the question of the possibility to create a tool similar to BRE but capable of technological decision support is a conclusion that it is necessary to combine two forms of knowledge presentation: declarative and procedural. It is also necessary to ensure the possibility of communication between this type of instrument and external data sources as well as various types of IT tools supporting specific technological decisions.

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