ITHEA

International Journal INFORMATION THEORIES & APPLICATIONS

2009 Volume 16 Number 4

International Journal
INFORMATION THEORIES & APPLICATIONS
Volume 16 / 2009, Number 4

IJ ITA is official publisher of the scientific papers of the members of the ITHEA® International Scientific Society

IJ ITA welcomes scientific papers connected with any information theory or its application.

IJ ITA rules for preparing the manuscripts are compulsory.
The **rules for the papers** for IJ ITA as well as the **subscription fees** are given on *www.ithea.org* .
The camera-ready copy of the paper should be received by http://ij.ithea.org.
Responsibility for papers published in IJ ITA belongs to authors.

General Sponsor of IJ ITA is the **Consortium FOI Bulgaria** (www.foibg.com).

International Journal "INFORMATION THEORIES & APPLICATIONS" Vol.16, Number 4, 2009

Printed in Bulgaria

Edited by the **Institute of Information Theories and Applications FOI ITHEA®**, Bulgaria,
in collaboration with the V.M.Glushkov Institute of Cybernetics of NAS, Ukraine,
and the Institute of Mathematics and Informatics, BAS, Bulgaria.

Publisher: **ITHEA®**
Sofia, 1000, P.O.B. 775, Bulgaria. www.ithea.org, e-mail: info@foibg.com

ISSN 1310-0513 (printed) **ISSN 1313-0463 (online)** **ISSN 1313-0498 (CD/DVD)**

COGNITIVE APPROACH IN CASTINGS' QUALITY CONTROL

Irina Polyakova, Jürgen Bast, Valeriy Kamaev,
Natalia Kudashova, Andrey Tikhonin

Abstract: *Every year production volume of castings grows, especially grows production volume of non-ferrous metals, thanks to aluminium. As a result, requirements to castings quality also increase. Foundry men from all over the world put all their efforts to manage the problem of casting defects. The authors suggest using cognitive approach to modeling and simulation. Cognitive approach gives us a unique opportunity to bind all the discovered factors into a single cognitive model and work with them jointly and simultaneously. The method of cognitive modeling (simulation) should provide the foundry industry experts a comprehensive instrument that will help them to solve complex problems such as: predicting a probability of the defects' occurrence; visualizing the process of the defects' forming (by using a cognitive map); investigating and analyzing direct or indirect "cause-and-effect" relations. The cognitive models mentioned comprise a diverse network of factors and their relations, which together thoroughly describe all the details of the foundry process and their influence on the appearance of castings' defects and other aspects. Moreover, the article contains an example of a simple die casting model and results of simulation. Implementation of the proposed method will help foundry men reveal the mechanism and the main reasons of casting defects formation.*

Keywords: *castings quality management, casting defects, expert systems, computer diagnostics, cognitive model, modeling, simulation.*

ACM Classification Keywords: *I.6.5 [Computing Methodologies - Simulation and Modelling] Model Development - Modeling methodologies*

Introduction

Every year production volume of castings grows, especially grows production volume of non-ferrous metals, thanks to aluminium. Aluminium and its alloys have been the prime material of construction for the aircraft industry, car production and also attractive in other areas of transport thanks to the combination of acceptable cost, low component mass, appropriate mechanical properties, structural integrity and ease of fabrication.

Aluminuim alloys are processed with the help of all possible techniques of metal casting. In order to choose the right technique all technical and economic requirements (casting size, weight, wall width, casting complexity, required quantity of castings) should be attended [VDS, 1988]. The most commonly used techniques are pressure die casting (about 58 % in 1998 in Germany), gravity die casting (about 33 %) and sand mould casting (9 %) [Drossel, 1999].

Because of continuous growing of castings output from aluminium alloys, requirements to the castings quality also increase. Aluminum casting alloys have a number of typical casting defects. Among them are building of oxides, porosity, misrun etc. By casting defect we understand a technical characteristics mismatch of produced castings and technical requirements which the castings should meet.

While we still get castings with defects that make castings more expensive, foundry men from all over the world put all their efforts to manage the problem of casting defects.

1. Identifying the Problem

Because of the high oxidation susceptibility, aluminium alloys form oxide films on the surface, which affect the quality of the melt and make it viscous. Consequently, inclusions of oxides can be observed in the form of casting defects. In practice the aluminium alloys, which tend to high oxygen content, also tend to high hydrogen content as well. High hydrogen content in the melt is one of the immediate causes of porosity defect. The other typical casting defect of aluminium alloys is misrun (when the melt become hard too early, before it reaches all edges).

Fig. 1. Casting defect - oxide film [Altenpohl, 1994]

The process of casting defects formation depends on a great amount of factors and parameters. Very often, these dependencies are very complex by their nature; they could only be described by numerous factors, which in their turn could have varying interactions with others. Moreover, we experience a lack of knowledge about the collection of factors in general and have limited opportunities of their quality understanding.

Nowadays we see a large number of simulation methods that work with complex dynamic systems and processes. The choice of a method depends on the level of complexity of a system and on the volume of information about it. Today there are four main groups of methods in the sphere of “fighting” with casting imperfections:

- the first method is based on the use of atlases of casting defects. Many research centers are still working on them. It is difficult to find right reasons with the help of such atlases, especially when there is more than one reason or more than one defect;

- the second method deals with classical expert systems. Though many scientific groups work on them, such kind of software systems does not give us an opportunity to observe the behavior of all system parameters when we want to improve values of some of them;

- the third group works on a so-called black box technology. The black box technologies comprise methods that are based for example on neural networks. Nevertheless, the problem of neural networks lies in the lack of transparency of the process of making inferences. This means that it is impossible to understand the grounds of the conclusion being made;

- the forth method is a simulation. This is a common method, when a system is represented by a number of differential equations, which describe energy conservation laws that occur in the system. Moreover, it is the most laborious and complicated method, which is also rather costly and time consuming.

Though simulation is the most powerful method very often there is no need to spend time and money to build a model. Frequently the problem lies in understanding of the occurring processes. Moreover, in the field of "fighting" with casting defects, it is impossible to build a fully adequate mathematical model, which summarizes all the factors and their interrelations. Even now, there are a lot of interferences, which are still not described mathematically and could only have verbal interpretation.

To solve the problem of understanding of processes that occurred the authors suggest using cognitive approach to modeling and simulation. The approach is based on the usage of cognitive maps in computer simulation. With the help of cognitive maps, it is possible

- to make visible and transparent all the occurred processes and the whole complex network of reasons of casting defect formation;

- give plausible results without a need to answer difficult questions about cause-and-effect relations;

- capture and visually present the structure of expert knowledge – a set of factors from the problem domain and cause-and-effect relations between them, –and also generate structure-related information about possible consequences [Axelrod, 1976];

- easily make certain evaluations [Axelrod, 1976].

It is very important in the area of "fighting" with casting defects, because the change of one parameter usually cause changes in other manufacturing parameters. Very oft it is very difficult to suppose the consequences of problem solving. Possibly a new problem (Fig.2)?

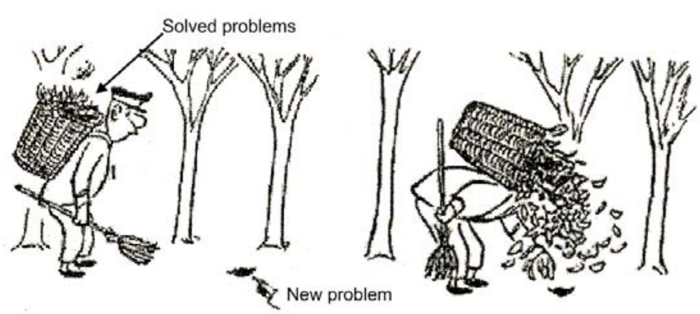

Fig. 2. Problem solving

The fight with casting defects can lead to undesirable after-effects: appearance of other imperfections, loss of time, money, resources and finally to loss of productivity. Cognitive modeling makes it possible to conduct fast and more or less exact quantitative virtual experiments with the help of proper software and to get the required information.

Cognitive approach gives us a unique opportunity to bind all the discovered factors into a single cognitive model and work with them jointly and simultaneously. Moreover, it is possible to use not only well-known exact interactions, but also interactions, which are only supposed to occur.

Cognitive maps were initially suggested by American psychologist Tolman E. C. to describe behaviour of mice [Tolman, 1948]. Later Axelrod R. used them in politics (model of British politics in Persia) [Axelrod, 1976]. Roberts F. used them in economics (model of energy consumption) [Roberts, 1986].

Commonly a cognitive map is represented as a directed graph G(V, A), where V - factors, A - cause-and-effect relations between factors.

Significant contribution to the development of cognitive maps' theory was made by B. Kosko [Kosko, 1992]. He proposed the most popular modification of cognitive maps - so-called fuzzy cognitive maps (FCM), where values of factors vary from -1 to +1 and some scale is in use.

Cognitive modeling has already been tested with socio-economic systems like regional economy management, industrial safety and so on [Kosko, 1992]. All such systems are complicated and semi-structured systems, which have a large quantity of interacting factors. These interactions could be changed dynamically. The system of casting defect formation has similar characteristics; therefore the cognitive approach should be rather efficient here.

Like many other scientists the authors see further development of cognitive maps' approach in the direction of joining them with fuzzy logic, where factors are linguistic variables and relations represent data banks of fuzzy rules.

Cognitive modeling has already been tested on complicated and semi-structured systems, which have a large quantity of interacting factors. The system of casting defect formation has similar characteristics; therefore the cognitive approach should be rather efficient here.

The method of cognitive modeling (simulation), discussed on the conference, should provide the foundry industry experts a comprehensive instrument that will help them to solve complex problems such as:

- predicting a probability of the defects' occurrence;
- visualizing the process of the defects' forming (by using a cognitive map);
- investigating and analyzing direct or indirect "cause-and-effect" relations.

2. Example of the Cognitive Model

For example, let us consider a cognitive map of AlSi12-alloy and die casting process. In our research, we investigate a great number of factors, which described properties of aluminium-alloy, die, work process-related parameters, work of personnel and machines. In order to arrange reasons of casting defect formation logically and evaluate system reasons a so-called Ishikawa diagram (cause-and-effect diagram; Fig. 3.) is used. In order to find all factors each group was analyzed in detail.

In the classical cognitive approach, all factors's values are qualitatively described (for example "weak", ""strong", "reasonably", "high", "low"). Each factor has an own scale from -1 to 1 and ranges within the scale, the boundary values of selected for the example factors are shown in the next table (Tab. 1). In spite of the fact, that some factors can be described quantitatively (like die temperature or width of coating) and others can be evaluated only qualitatively (like continuity of the metal-flow or competence of personal), all factors in the example will be described qualitatively and scaled from -1 to 1.

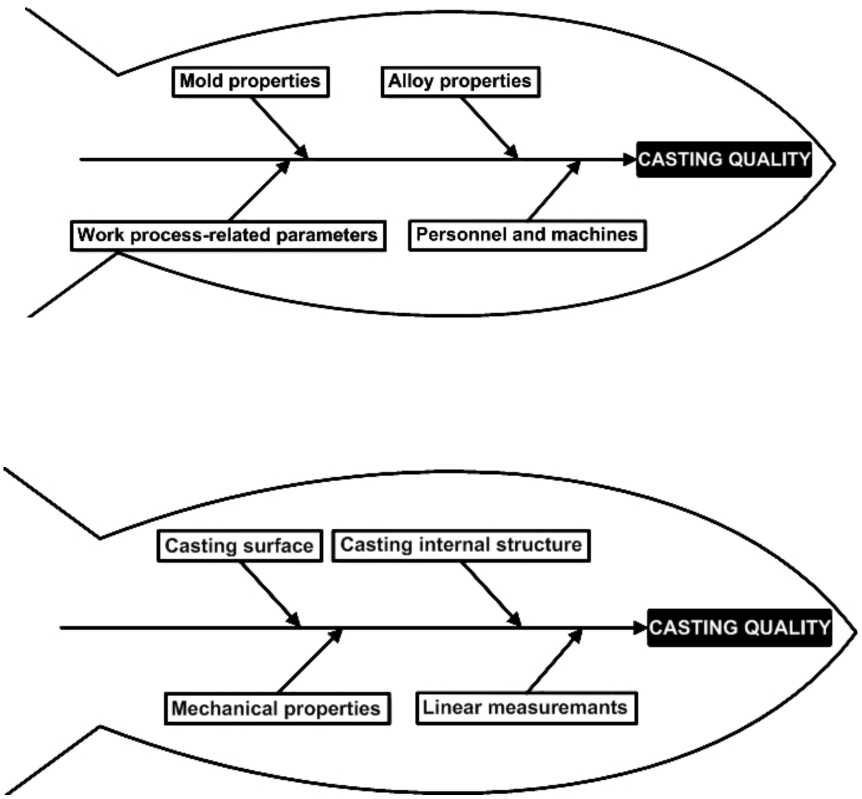

Fig. 3. General view of the Ishikawa-diagrams

Table 1. Boundary values of selected factors

Name of the factor	Min value(-1)	Max value(+1)	Unit
Die temperature	low (300)	high (400)	°C
Pouring rate	low	high	m^3/s
Width of coating	thin (0,1)	thick (0,2)	mm
Die durability	low	high	Castings
Width of the die wall	thin (2*D, D-wall thickness of the casting)	thick (5*D, D-wall thickness of the casting)	sm.
Shrinkage of the alloy	high (0,8 %)	small (0,5 %)	%
Fluidity	low	high	mm
Mouldfilling ability	low (0,1)	high (1,1)	mm-1
Fe content	low (0,0)	high (1,0)	%

Mn content	low (0,001)	high (0,4)	%
Cu content	low (0,0)	high (0,1)	%
Gas absorbtion of the alloy	low	high	-
Casting strength	low (110)	high (150)	N/mm^2
Porosity	low	high	-
Cold cracks	low	high	-
Misrun	low	high	-
Die ventilation	poor	good	-
Width of the casting wall	thin	thick	sm.
Internal stress	low	high	-
Surface conditions of the die	bad (damaged)	good (undamaged)	-
Evaporation of coating	high	poor	-
Poring temperature	low (680)	high (780)	°C
Oxide	low	high	-
Oxide in melt	little	many	-
Purity of metal melt	bad	good	-
Idle time of the melt	short (10 min)	long (120 Min)	min
Surface conditions of the tank	dirty	clean	-
Melting time	short	long	min
Melt temperature in idle time	low (780)	high (800)	°C
Oxide formation during mold-filling	low	High	-
Pouring height	low	high	sm
Speed of the melt in the pouring gate	low	high	sm/s
Cross-section of the pouring gate	small	big	sm^2
Air absorption during pouring	poor	high	-
Fullness of the pouring gate	empty	full	-
Competence of personal	low	high	-
Continuity of the metal-flow	unsteady	steady	-

If there are no quantitative data about the interactions, it is possible to use a qualitative value (strong, moderate, weak) to define the interactions together with the Harrington's scale [Diligensky, 2004] from -1 to +1. We used the following Harrington's scale to measure the interaction force for all factors not to complicate the model: "lightly"-[0-0.2], "weakly"-[0.2-0.37], "moderate" - [0.37-0.63], "essentially" - [0.63-0.8], "strong" - [0.8-1].

Using qualitative relations, we can also distinguish positive and negative interactions. In other words, a positive interaction shows us that a rise of the factor, which is at the beginning of the arrow, increases the factor value on the arrow end; a negative interaction on the contrary shows us that a rise of the factor, which is at the beginning of an arrow, decreases the factor value on the arrow end.

Example the qualitative relations according to Harrington's scale:

- purity of metal melt strongly decreases (-1) oxides in the melt;
- temperature difference in the die essentially decreases (-0.7) die durability;
- Cu-presents essentially decreases (-0.7) shrinkage of the alloy;
- pouring temperature essentially increases (0.8) fluidity of the melt;
- continuity of the metal-flow lightly increases (0.2) oxide formation during mold-filling.

An example of possible verbal interpretation sounds: "moderate increase of the die ventilation strongly increases the probability of porosity defect" (Fig. 3).

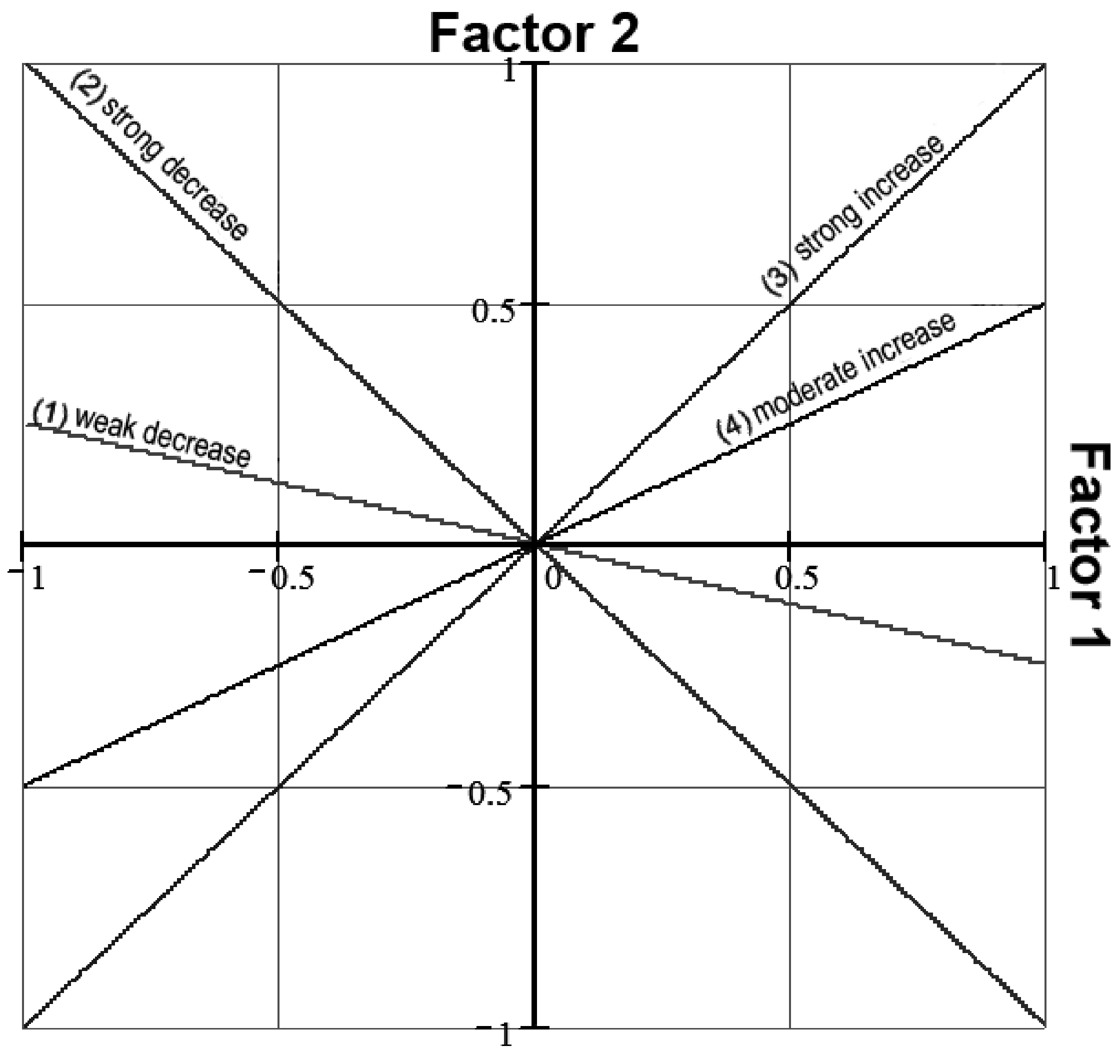

Fig. 3. Qualitative interactions

A fragment of classical cognitive map is shown on Fig. 4. The fragment consists of 38 factors and even more interactions. In the given model, many factors are not attended to reduce a model size for the article.

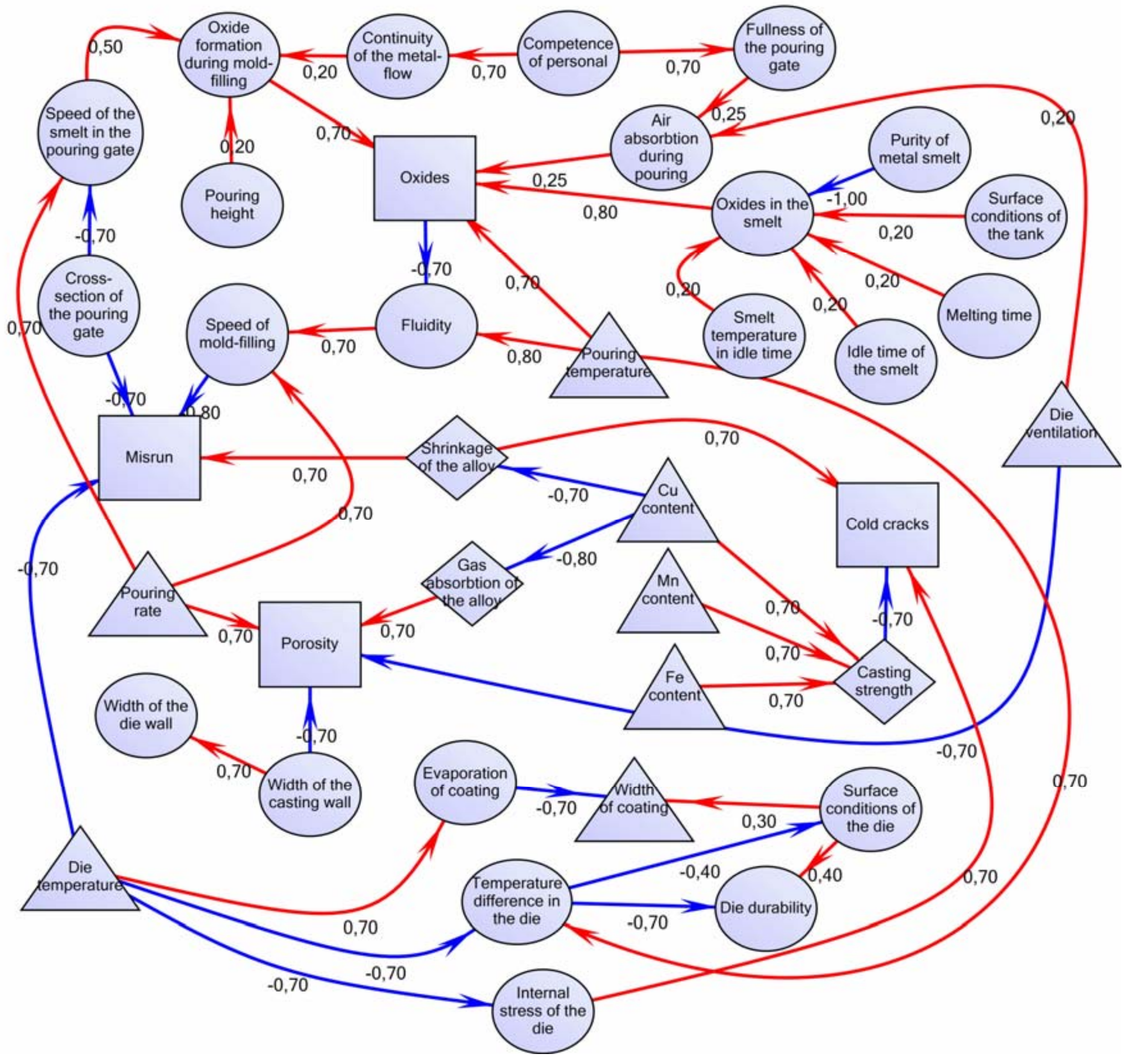

Fig. 4. Fragment of the cognitive map with 38 factors (∆ - control factors, ☐ - target factors, ○- other factors)

Among these factors, we can choose so-called target factors, which should alter in a desired direction (shown with squares at Fig. 4). Moreover, we can also select so-called control factors (shown with triangles in Fig. 4), which values we can change in order to achieve desired directions of target factors.

The information about factors is represented in the software system as a matrix. This allows us to run a simulation, which virtually shows possible consequences of alterations of one or more factors.

3. Simulation Example

Let us demonstrate a simple simulation example on the above-mentioned model. The behavior of some factors when adding Cu into the alloy is observed. It can be observed, that the addition of Cu at first influences the gas-absorption ability of the alloy, shrinkage of the alloy and casting strength. Alterations of these factors lead in their turn to the reduction of misruns, porosity and cold cracks. The results of simulation are shown in Fig. 5.

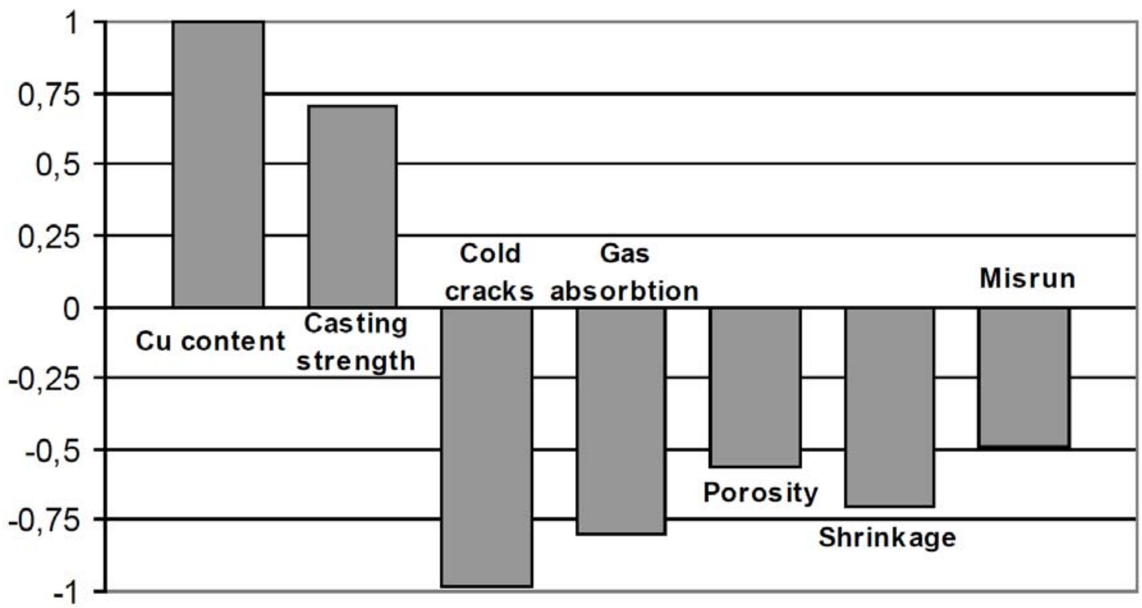

Fig. 5. Simulation example “Cu content – cold cracks, porosity, misrun”

The next example will demonstrate conflicting goals. This time the factor “pouring rate” is chosen. If we look at the graph (Fig. 4), we can see that the increasing of pouring rate of the melt will increase speed of the melt in the pouring gate, which in its turn will lead to increase of oxide formation during mould-filling and consequently we could get oxide film casting defect (see Fig. 6). Otherwise, the increase of pouring rate of the melt increases speed of mould filling, what in its turn decreases the probability of misrun.

This example illustrates how the “fight” with one casting defect can influence on the others. Therefore, it is highly important to consider the whole network of factors, but not concentrate on a single factor or even a group of factors.

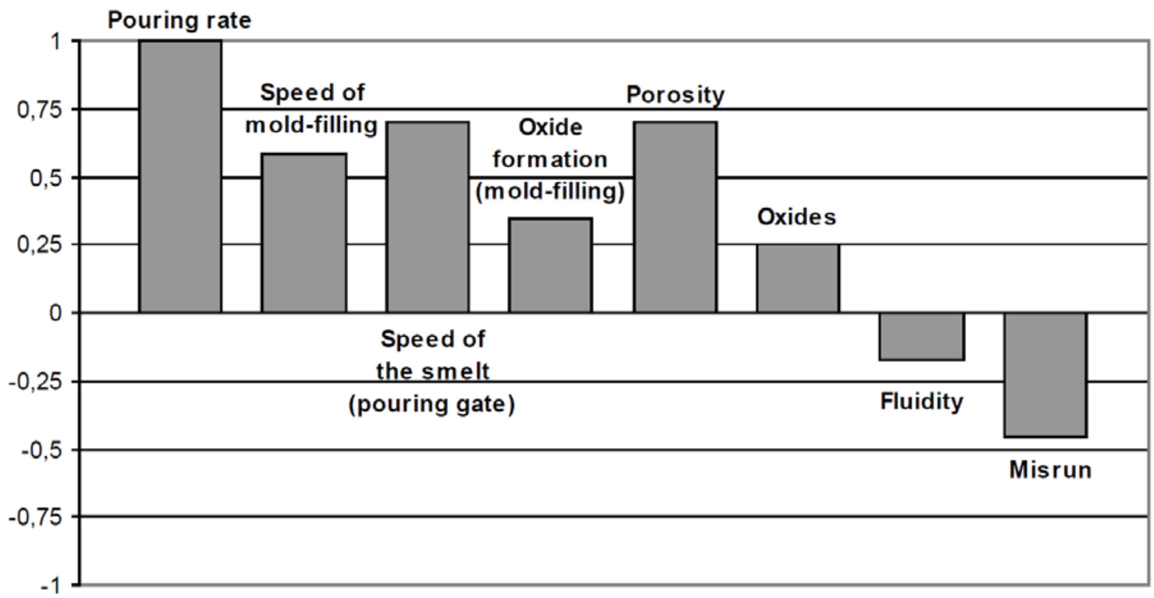

Fig. 6. Example “pouring rate – oxides, porosity, misruns”

4. Software

In order to facilitate and simplify the process of creating this cognitive model of casting defects’ formations (and cognitive models in general) we use a software analytical system "Strategist" (Fig. 7).

Fig. 7. Logo of “Strategist”.

This software is developed in the context of doctoral thesis at the institute of mechanical engineering at the technical university Freiberg and Volgograd state technical university. The „Strategist“ is used for visual representation of complex casual relations between factors during the analysis of complicated semi-structured problems. With the help of this software system all the available experience and knowledge of the factory employees and experts can be easily transferred into factors and interactions.

The software is designed for simulation of the further development of the systems situation with or without control actions. It is also assigned to simulate scenarios, to create and analyze different strategies, with are rather costly to realize in a real system (Fig. 8).

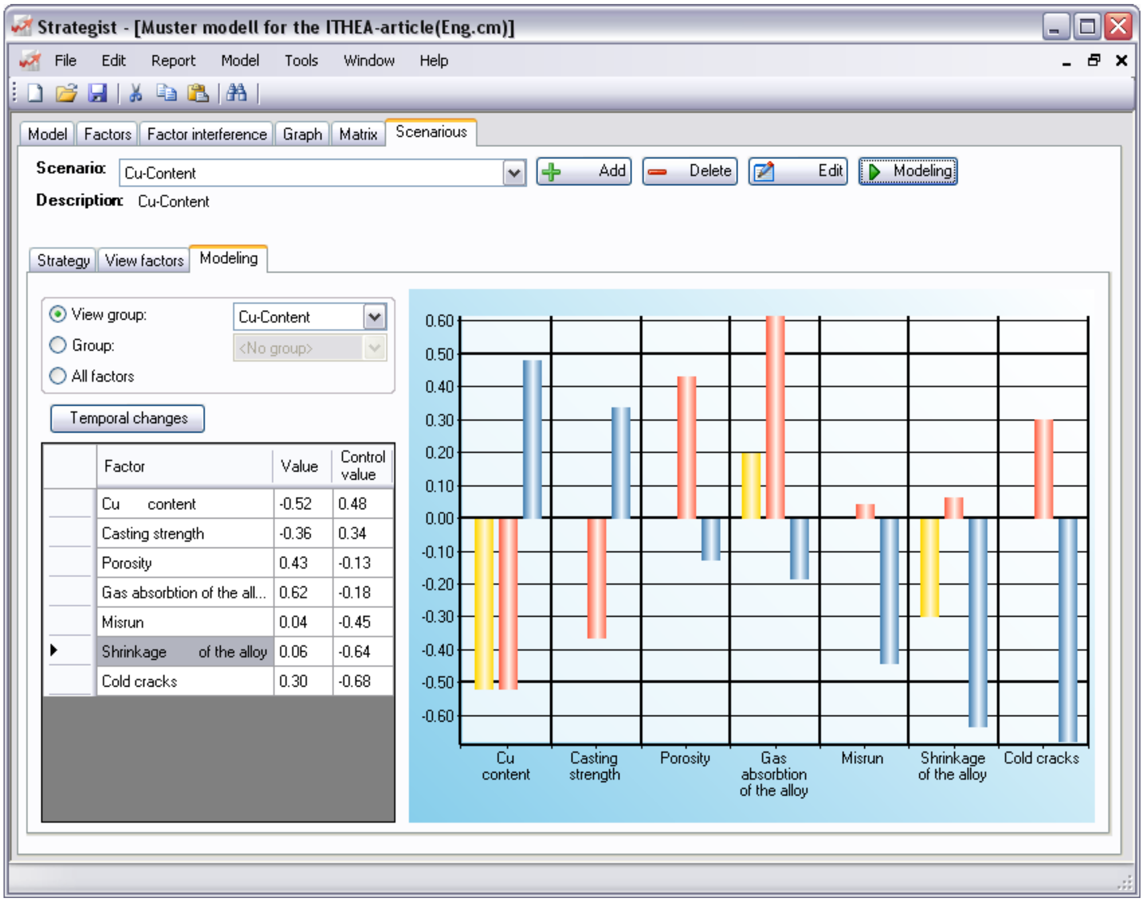

Fig. 8. Window of the simulation results in “Strategist”

Besides the “common” features of the cognitive simulation (representation of the model as matrix or graph, self-development, development with control, and so on) in “Strategist” are also realized some new like:

- determination of the interconnections between factors with the help of correlation analyses on the basis of the statistical information;
- determination of the common (direct and indirect) influences of one factor to all others and of the all factors to the selected one;
- visual coloration of the influences levels on the graph;
- search of all possible chains between 2 selected factors;
- Pareto-analyze of the interconnections between all the factors.

The user can choose from 4 different methods to build a cognitive map: using a graph, using connected lists of factors, using a matrix or using integrated library of factors.

5. Further Scientific Plans

With the help of the common cognitive map of the defects formation of the AlSi12 the authors are going to analyze indirect influences between factors deeper. The authors plan to analyze three types of the influences separately: “cause” – “casting defect”, “casting defect” – “casting defect”, “cause” – “cause” (Fig. 9). Such kind of relations has hardly ever been investigated and analyzed. But with the help of cognitive approach we have got a unique opportunity to see the real picture with all “cause-and-effect” relations – either direct or indirect.

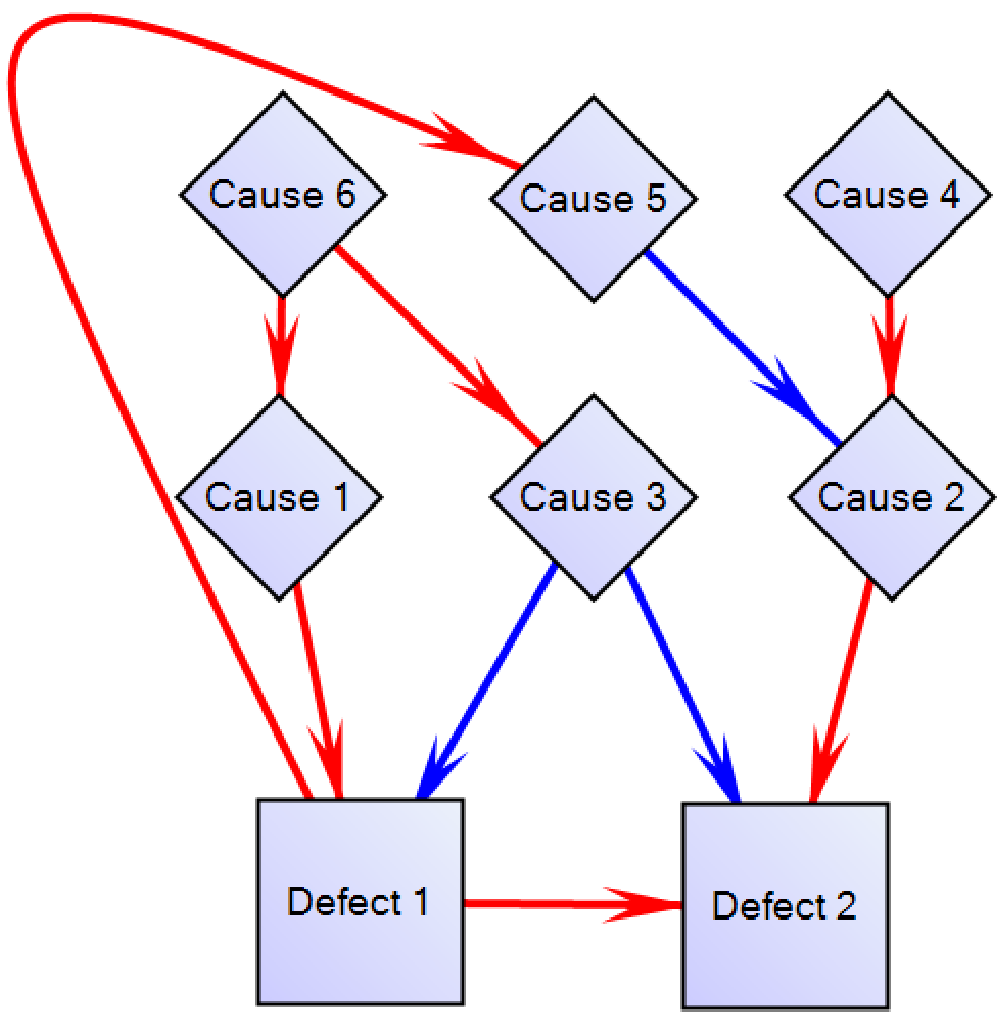

Fig. 9. Possible relations

Conclusion

So, the software system, which is being developed and improved, could be used by foundry men in their every day practice and by experts or managers in making fast decisions without a need to conduct long tests and complicated researches.

One of the main advantages of the proposed method is that a foundry man can extend a cognitive model and improve results of simulation himself (without any help from the outside), according to his own knowledge and experience about castings formation and their avoidance. The use of the cognitive approach helps us to manage a large quantity of factors. It is highly competitive in the situations, when other methods could either be very expensive or do not show the logic of the occurred processes. This method will help foundry men to reveal the mechanism and the main reasons of casting defects' formation and take preventive measures in time.

Nowadays authors make researches in different areas of the foundry process:

- aluminiun die casting;
- penetration defects by cast iron in sand forms;
- aluminium high pressure casting.

The authors continuously improve the software adding new tools and functions to make the cognitive approach widely available.

Acknowledgements

The authors would like to acknowledge financial support, provided by the DAAD (Deutscher Akademischer Austausch Dienst - German Academic Exchange Service) in the form of research grants.

Bibliography

[VDS, 1988] Aluminium Gusslegierungen. VDS – Vereinigung deutscher Schmelzhütten. ISBN 3-87260-092-3. 5. Auflage 1988.

[Drossel, 1999] G. Drossel, S. Friedrich, etc. Aluminium-Zentrale e.V., Aluminium-Taschenbuch. 15. Auflage. Band 2: Umformen von Aluminium Werkstoffen… ISBN 3-87017-242-8. 1999.

[Altenpohl, 1994] D. Altenpohl. Aluminium von innen. Das Profil eines modernen Metalles. 5. Auflage. Aluminium-Verlag, Düsseldorf, 1994. ISBN: 3-87017-235-5.

[Diligensky, 2004] Diligensky N.V., Dimova L.G., Sevastyanov P.V. Nechetkoe modelirovanie i mnogokriterialnaya optimizaciya proizvodstvennih system v usloviyah neopredelennosti: tehnologiya, ekonomika, ekologiya. Moskva, «Izdatelstvo Maschinostroenie n. 1», 2004

[Tolman, 1948] E. C.Tolman. Cognitive maps in rats and men. Psychological Review, 55, 189-208, (1948).

[Axelrod, 1976] Axelrod, Roberts (ed.), Structure of Decision (Princeton, NJ: Princeton University Press, 1976).

[Kosko, 1992] Kosko, Bart, Neural networks and fuzzy systems, a dynamical systems approach to machine intelligence (Englewood Cliffs, NJ [u.a.], 1992)

[Roberts, 1986] Roberts, Fred, Discrete mathematical models with application to social, biological and environmental problems (Rutgers University, Prentice-Hall, Inc, Englewood Cliffs, NJ, 1986)

[Brunhuber, 1958] Ernst Brunhuber. Leichtmetall- und Schwermetall- Kokillenguss. Fachverlag Schiele und Schön GmbH, Berlin.1958

[Schneider, 1986] Philipp Schneider. Kokillen für Leichtmetallguß, Gießerei-Verlag.1986.

[Irmann, 1959] Dr.-Ing habil. Roland Irmann. Aluminiumguss in Sand und Kokille. Aluminium-Verlag GmbH Düsseldorf 1959

[Polyakova, 2005] Polyakova I.A., Kamaev V. A., Zabolotsky M. A..,Tikhonin A. V., region's situation analysis and development management with the help of cognitive modeling IT in science, education and business: Works of international conference, Gurzuf, 2005

[Frank, 1993] Gregory, Frank: Cause, Effect, Efficiency and Soft Systems Models, in: The Journal of the Operational Research Society, Vol. 44, No. 4, New Research Directions (Apr. 1993), S. 333-344

Authors' Information

Polyakova, Irina *– – PhD student; Institute of mechanical engineering Technical University Bergakademie Freiberg, Bernhard-von-Cotta-Strasse 4, D-09596 Freiberg; e-mail: ipolyakova@gmail.com*

Bast, Jürgen *– Professor Dr. Eng., Head of the Department, Institute of Mechanical Engineering Technical University Bergakademie Freiberg, Bernhard-von-Cotta-Strasse 4, D-09596 Freiberg; e-mail: bast@imb.tu-freiberg.de*

Kamaev, Valeriy *– Professor Dr., Head of the CAD Department, Volgograd State Technical University; e-mail: cad@vstu.ru*

Kudashov, Natalia *– PhD student; Institute of mechanical engineering Technical University Bergakademie Freiberg, e-mail: natalia@kudaschov.de*

Tikhonin, Andrey *– PhD student; Volgograd State Technical University; e-mail: andrey.tikhonin@gmail.com*