# COGNITIVE APPROACH IN CASTINGS' QUALITY CONTROL

Jürgen Bast, Valeriy Kamaev, Irina Polyakova,
Andrey Tikhonin, Maxim Zabolotsky, Natalia Kudashov

**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. In this article the authors present an approach based on the use of cognitive models that help to visualize inner cause-and-effect relations leading to casting defects in the foundry process. 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, modelling, simulation.*

*ACM Classification Keywords: I. Computing Methodologies - I.6 Simulation and Modelling - I.6.5 Model Development - Modelling methodologies*

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## Introduction

By casting defect we understand a technical characteristics mismatch of produced castings and technical requirements which the castings should meet.

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. 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. The issue of reducing casting defects is vital for the foundry industry.

The quality of castings 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.

The presence of intricate interactions (which can also change dynamically or depend on other factors) and at the same time insufficient information about other relations make the understanding of relations between factors more complicated.

## Existing methods and the proposed method of problem solving

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 methods in the sphere of "fighting" with casting imperfections:

1) the first method is based on the use of atlases of casting defects. Many research centres 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;

2) 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 behaviour of all system parameters when we want to improve values of some of them;

3) 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;

4) the forth method is simulation. This is a common method, when a system is represented by 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.

In the field of “fighting” with casting defects, it is impossible to build a fully adequate mathematical model, which summarises all the factors and their interrelations. Even now, there are a lot of interferences, which are still not mathematically described and could only have verbal interpretation. Taking into consideration the results of the conducted analysis of existing methods and their disadvantages in the sphere of “fighting” with casting defects, the authors are going to use a new method of informational representation – a cognitive map.

Cognitive modelling 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 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 modelling has already been tested with socio-economic systems like regional economy management, industrial safety and so on [Polyakova, 2005]. 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 simulation is an approach, which is based on the use of cognitive maps in computer simulation. With the help of cognitive maps, it is possible to make visible and transparent all the occurred processes of casting defect formation. Moreover, it is possible to use not only well-known exact interactions, but also interactions, which are only supposed to occur.

The visual representation of a cognitive map gives the possibility to see clearly the whole complex network of reasons of casting defect formation. This visualization helps foundry man to find rapidly all the weighted reasons of defects.

## Cognitive modelling example

For example, let us consider a cognitive map of AlSi12-alloy and die casting process. In our research we investigated a great number of factors, which described properties of alloy, mould, work process-related parameters, work of personnel and machines and also factors, which described casting quality (structure, mechanical properties, measurements and casting surface). We have collected a considerable catalogue of factors. 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.

In order to arrange reasons of casting defect formation logically we used a so-called Ishikawa diagram (or a fishbone diagram, also known as a cause-and-effect diagram) [Frank, 1993]. This diagram helps to discover several levels of reasons of a problem. We used it in order to find and evaluate system reasons of casting defects.

Afterwards, we developed a cognitive map on the basis of the factors that had been founded with the help of Ishikawa diagrams (Fig. 1).

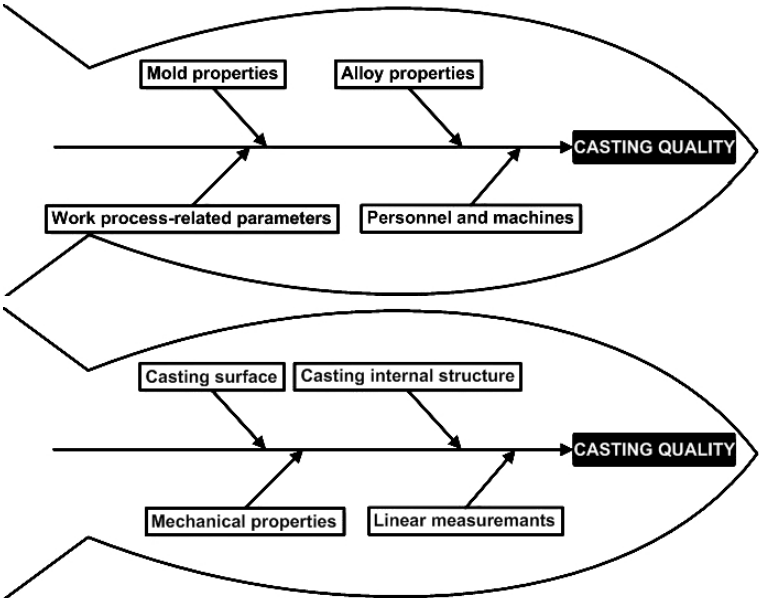

*Fig. 1. General view of the Ishikawa-diagrams*

Frequently, it is quite a challenge to describe how factors interact with each other. Moreover, we do not have exact information about the character of this interaction. But we know that, for example, “if the die ventilation is insufficient, the probability of porosity defect will increase”. So, we do not have any well-defined relation or mathematical equation. In such case we can take an advantage of cognitive modelling, which supports qualitative interactions and can help us to analyze complex systems with the above mentioned type of relations.

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. An example of possible verbal interpretation sounds: “moderate increase of the die ventilation strongly increases the probability of porosity defect”.

A fragment of classical cognitive map is shown in Fig. 3. The fragment consists of 29 factors and even more interactions. In order to facilitate and simplify the process of creating this cognitive model of casting defects’ formations (and cognitive models in general) we designed a software system. 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.

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.

For example, on the cognitive map in Fig. 3 we can see that the factor “zinc” negatively influences the factor “hot cracking” and consequently decreases it, while the element titanium rises up the probability of “hot cracking”.

Among these factors we can choose so-called target factors, which should alter in a desired direction (shown with squares at Fig. 3). Moreover, we can also select so-called control factors (shown with triangles in Fig. 3), which values we should 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.

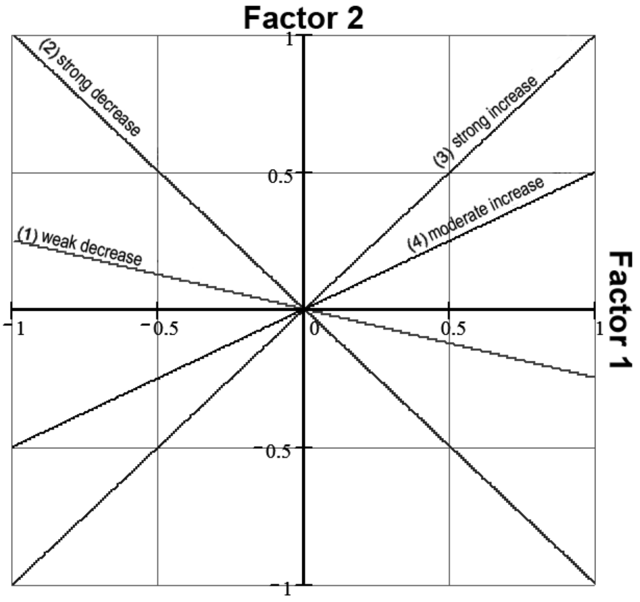

*Fig. 2. Qualitative interactions*

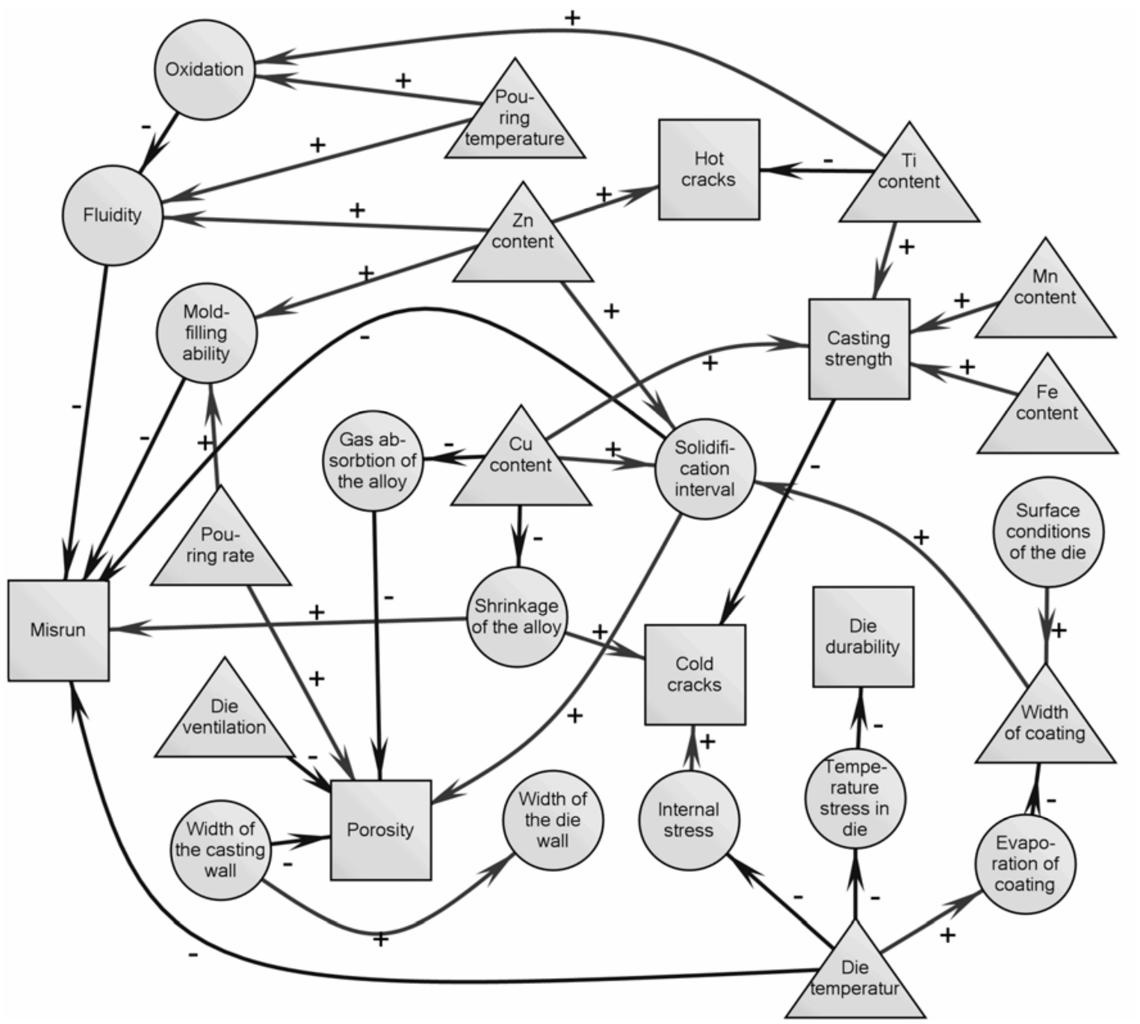

*Fig. 3. Fragment of the cognitive map with 29 factors (Δ - control factors, □ - target factors, ○- other factors)*

## Simulation example

To demonstrate a simple simulation example on the above mentioned matrix let us simplify all the interactions in our cognitive model and to make either -0.5 (for all negative) or +0.5 (for all positive).

For example, let us observe the behaviour of some factors when adding zinc into the alloy. We can observe that the addition of zinc at first influences the fluidity and mould-filling ability of the alloy. Alterations of these factors lead to probable reduction of misruns. The results of simulation are shown in Fig. 4.

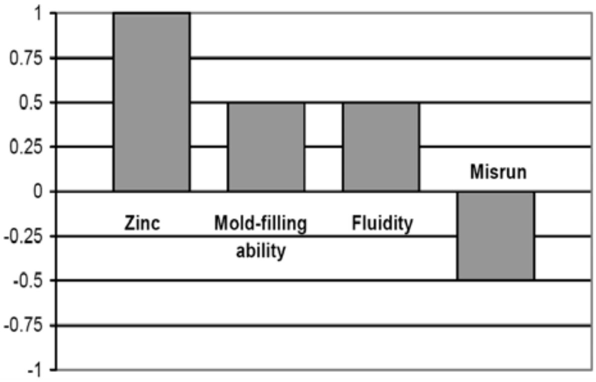

Fig. 4. Simulation example “zinc – misrun”

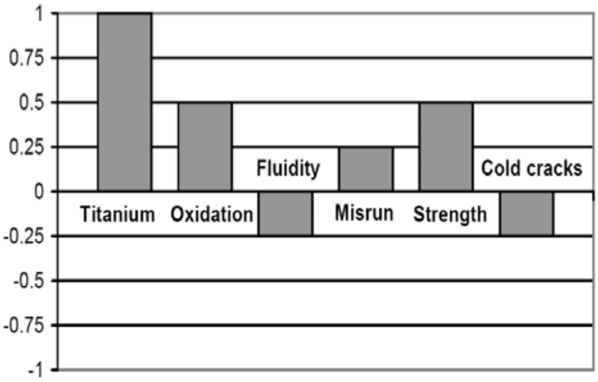

Fig. 5. Example “titanium– misruns and cold cracks”

The next example will demonstrate conflicting goals. This time we choose the factor titanium. If we look at the graph, we can see that the addition of titanium into the alloy will increase oxidation, which in its turn will lead to reduction of fluidity and consequently we could get misruns (see Fig. 5).

Otherwise, the presence of titanium in the alloy increases strength, what in its turn decreases the probability of cold cracks.

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

## 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 the foundry men to reveal the mechanism and the main reasons of casting defects’ formation and take preventive measures in time.

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## Authors' Information

***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*

***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*

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

***Zabolotsky, Maxim*** *– PhD student; Volgograd State Technical University; e-mail: mxms@rbcmail.ru*

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