ABOUT THE ROLE OF MATERIAL SCIENCE AND INFORMATICS SCIENCE IN THE PROCESS OF TECHNOLOGICAL MODES DESIGN

Prof. Nikolay TONTCHEV, D. Sc., Ph. D.
tontchev@gmail.com tontchev@vtu.bg

I want to introduce **myself** to You.

I am Nikolay Tonchev from Bulgaria.

I am a Mechanical Engineer – a Professor in Material Science and Materials Technology.

My main specialty is plastic deformation but for more than 20 years I have been dealing with the problems of modeling and optimization of technological processes.

All of my research is on the **Research** Gate.

https://www.researchgate.net/profile/N_Tontchev

N. Tontchev

6.9 · Materials Science, · Edit

Overview | Contributions | Info | Stats | Scores | Research Interests

Introduction

Nikolay Tontchev received his MSc in Technology of Materials from the Technical University of Sofia in 1985 and PhD on Processes Deformation in Sheet Metals from the Technical University of Sofia in 1991. He habilitated as a Professor in Material Science and Technology in 1997. Currently, he is with the Transport University of Sofia, Department of Materials Science.

Skills and expertise (46)

Material Characterization | Materials | Mechanical Properties | Mechanical Behavior of Materials

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After my doctoral dissertation in various collectives I have developed more than 80 **papers**.

On this page **there** can be found my scientific and applied contributions, **some** of my achievements that I have worked **on** with colleagues.

They have always been **related** to a complex of properties, as we apply multicriteria optimization to solve practical **problems**.

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SCIENTIFIC AND APPLIED CONTRIBUTIONS With Autor Prof. Nikolay Tontchev

May 2014
DOI · 10.13140/RG.2.2.31148.56963

Projects · Approach for metallurgical design

N. Tontchev

The team I manage works in two directions:

New algorithms to examine the complex of properties

PROJECT: MulticritEria Genetic Algorithms (MEGA) ALLoysDESIGN At

October 2015

N. Tontchev

Genic, AHP + Genetic algoritms for complex properties

One of our algorithms for evaluating properties uses AHP. We have chosen a strategy whereby we reduce the **multicriteria** task to one-criterion

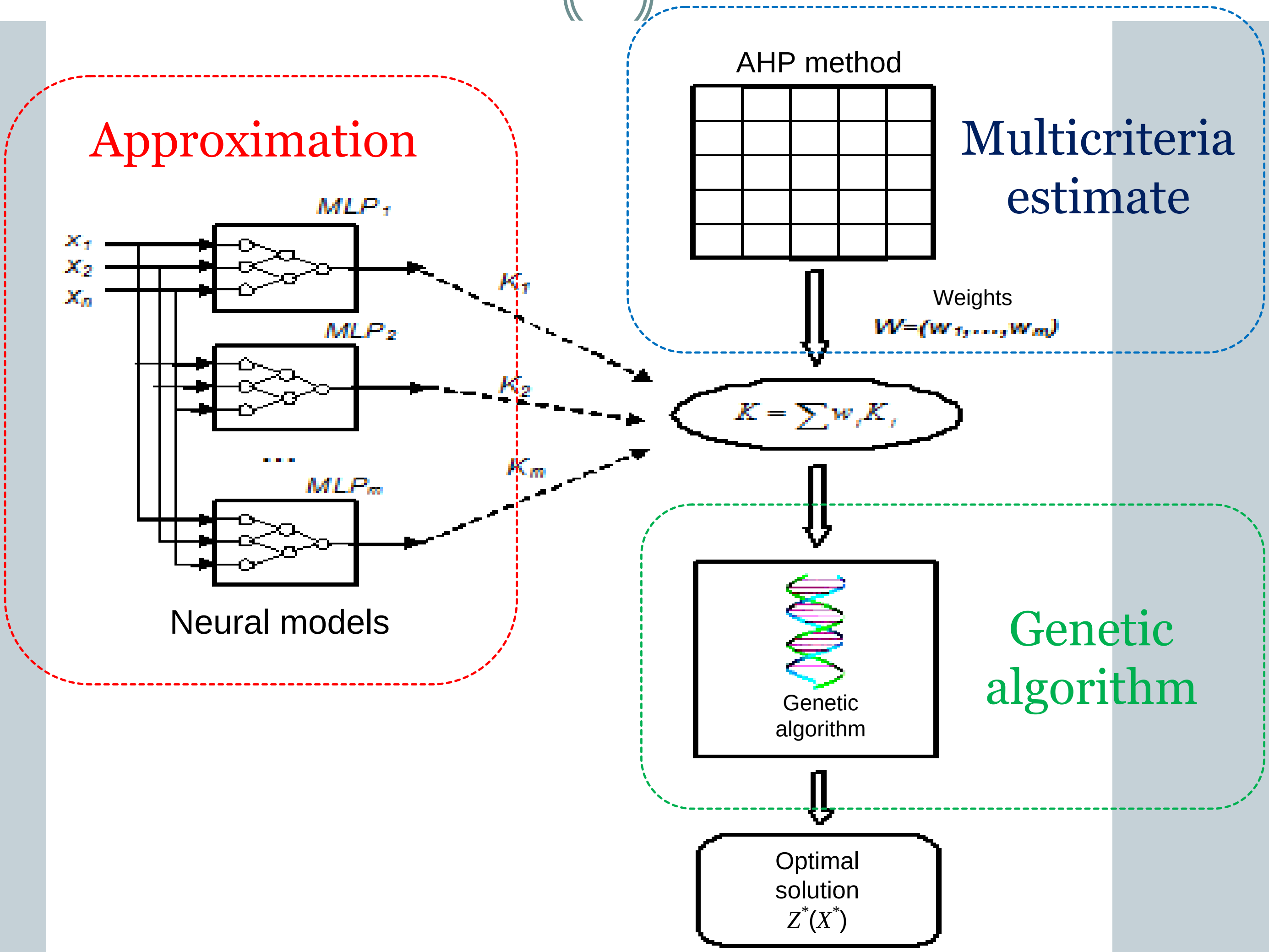
The AHP method introduces the criteria weights.

Then, a **generalized** matrix / array is constructed with each weight and each criterion.

The genetic algorithm determines the optimal value of the array and the corresponding input parameters.

The algorithm is adapted to use neural models.

Architecture of the model



Approach and architecture of the model

The used model combines three basic components:

- **Approximation** of dependencies between physico-mechanical characteristics of the alloys and their chemical composition with neural models;
- **Multicriteria assessment** of the constructive preferences of the physico-mechanical properties of the alloys;
- **Multicriteria optimization** of the chemical composition of the alloy respective to the defined constructive preferences.

Article Full-text available

Robust bi-criteria approach to optimize the composition and properties of alloy steels

June 2013

Projects · Approach for metallurgical design

N. Tontchev · Y. Kalev

We apply the Taguchi method for determining quality in mechanical engineering.

Taguchi's Quality Engineering Handbook

Genichi Taguchi
Subir Chowdhury
Yuin Wu

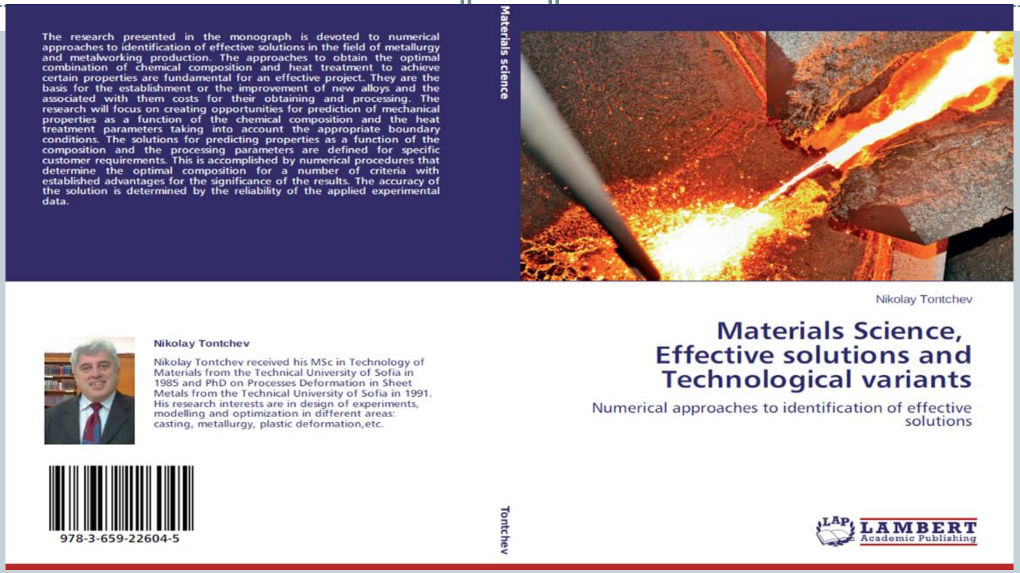
Associate Editors
Shin Taguchi and Hiroshi Yano

Our guide in this direction is Taguchi's famous book.

Applying the approach that I am going to introduce to You today, there are many common features with Taguchi's approach.

The experience I will give to Your colleagues will be **sufficient** and they will be easy to carry out this kind of tasks.

Generalization of methods for metallurgical design in iron-based material



My second dissertation was related to the optimization of the chemical composition of steels in the heat-treated state – hardening and high-temperature recovery.

This **research** was published in Germany as my monograph.

The theoretical explorations were investigations were confirmed in practice.

- In this monograph, most of my modern computational methods are found.
- The theoretical algorithms and programs **for** one kind of alloy can easily be re-edited for another.
- My explorations are on titanium and magnesium alloys only theoretical.
- I have no base where I can perform the experiments

This lecture contains:

1. Introduction
2. Most of the solved examples with my approach.
3. Steps in solving problems using the approach.
4. Key features of the approach
5. Conclusion**(s)**

Introduction

Problems of Material Science are complex.

There is a convergence between Informatics/Computer Science and Material Science.

Methods created by Informatics/Computer Science are successfully applied for solving Material Science problems.

On this basis, the approach that I will tell You today is developed.

Introduction

Modern design of technological processes uses the experiment only to verify the result of an optimal numerical simulation.

The implementation of the simulation is based on a well-explored theory,

The research is based on a real, reliable experiment.

For this reason, the deviations of the theoretical results from the real [ones] are within the statistical error.

Therefore, I trust this method because it uses reliable experimental data.

Introduction

The approach is suitable for collecting a complete base with respect to the input parameters, in which they change in a certain range.

For each combination of input parameters, one or more quantities are controlled.

My research partners that I will introduce to You were:

- **Bulgarian Academy of Sciences – Institute of Metals Science.**
- **Technical University of Sofia**
- **Military University of Veliko Tarnovo**
- **Technical University of Rousse.**

The experiments on all the research that I will report today have been conducted in various doctoral dissertations.

After the finish of the dissertations, each of the authors himself considered it necessary to apply a multi-criteria approach to determine optimal regimes or the optimal composition.

That's why You will know if I can not answer some technical details about the processes themselves.

Introduction

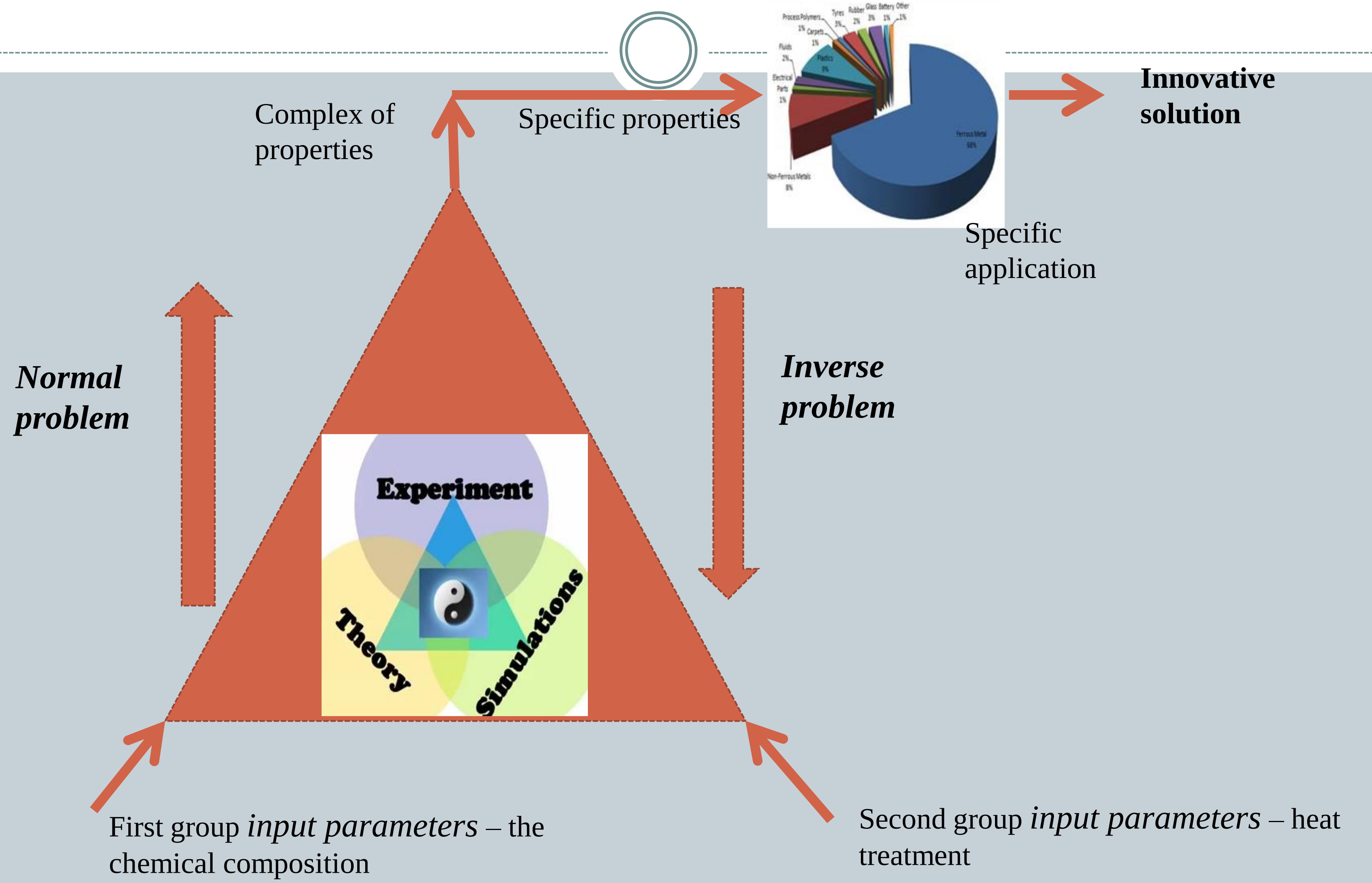
The main problems in Material Science are two:

Selection of material or processing mode for given performance properties – a problem known as a reverse task;

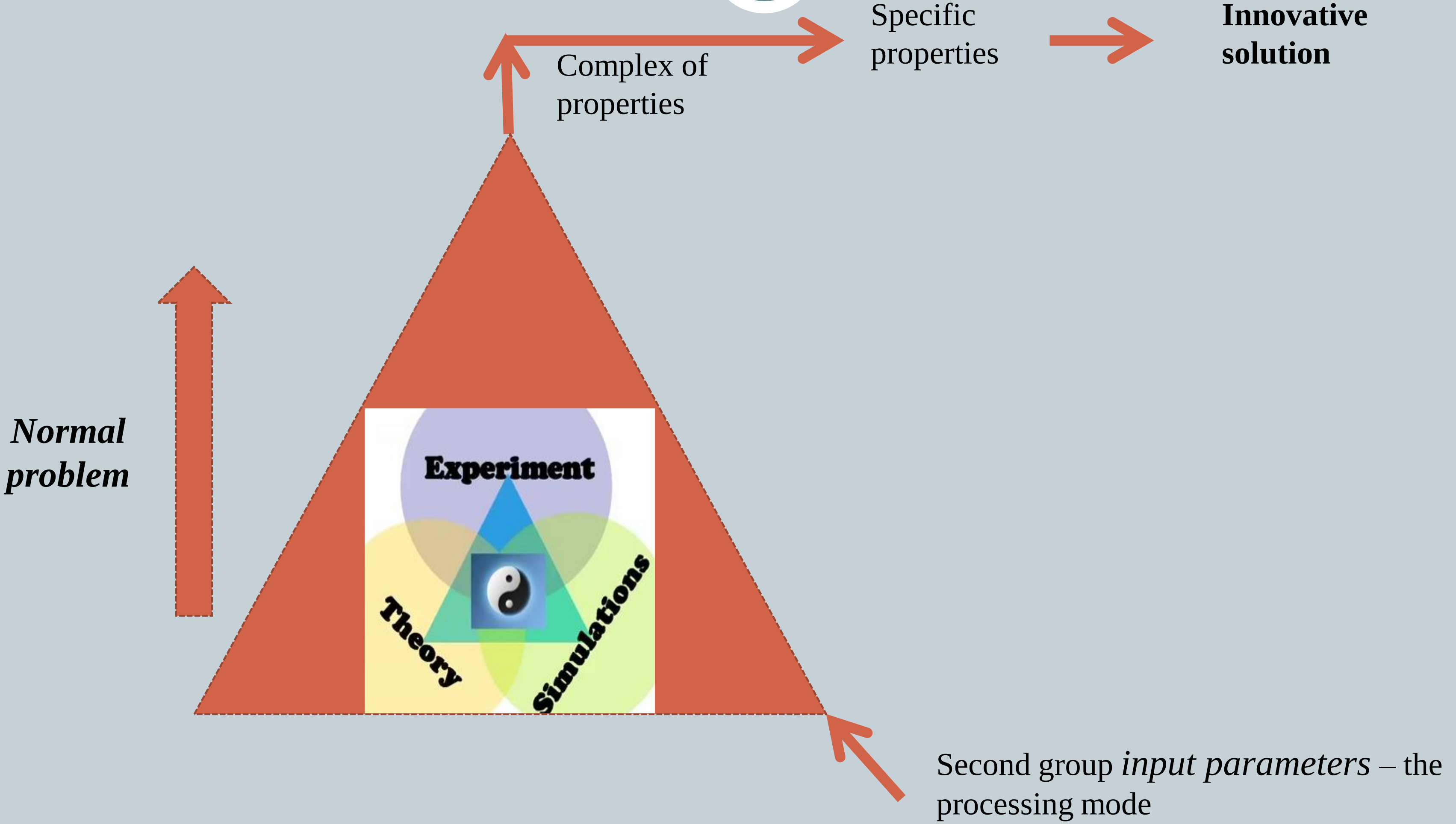
What anything can be used for specific material with specific processing. - a problem known as a straightforward task

As I speak to specialists dealing with foundry problems, I chose the first problem to be casting.

The subject of materials science with a focus on optimization and decision making



First application of the normal problem with an example from the domain of casting



The innovative solution of this example must determine the technological-mode parameters so that the strength properties in the separate sections must have the relatively best mechanical properties

BULGARIAN ACADEMY OF SCIENCES

INSTITUTE OF METAL SCIENCE, EQUIPMENT AND TECHNOLOGIES WITH HYDRO- AND AERODYNAMICS CENTRE "ACAD. A. BALEVSKI"

http://ims.bas.bg/projects/?lang=en

The department disposes of specialized machines for gas counter-pressure casting, presses for direct and indirect squeeze casting, machines high pressure casting, die-casting machines, furnaces for precise heat treatment of aluminum alloy castings, apparatuses and equipment for technological processes control.

In my casting problem, my research partner was the Institute of Metal Science at the Bulgarian Academy of Sciences.

- **There are 12 departments in this institute.**
- **You can get information about him from its site.**

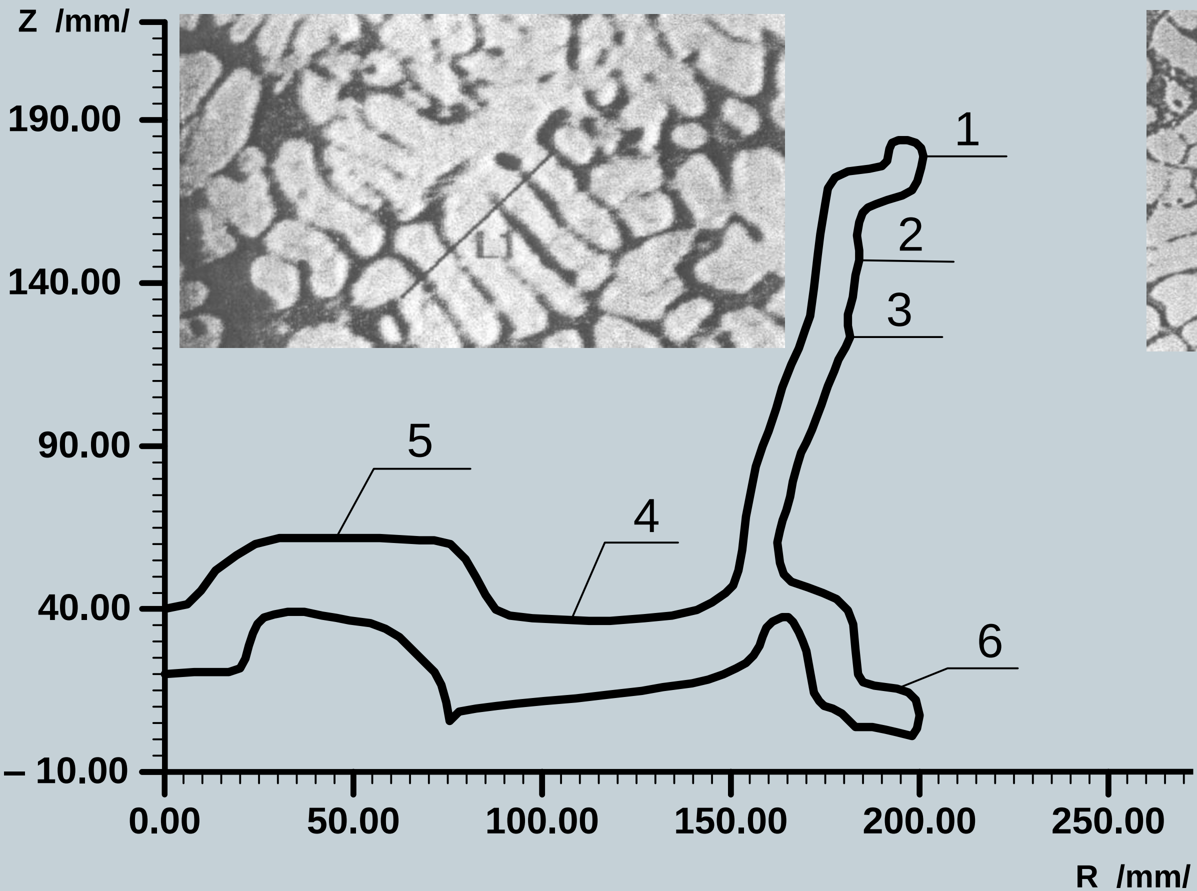
http://ims.bas.bg

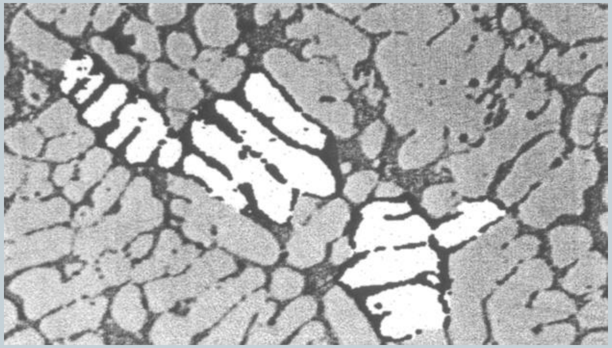
- **I can assist You in all matters with this Institute.**
- **The equipment we used was at the Institute.**
- **It is a gas counter-casting machine.**

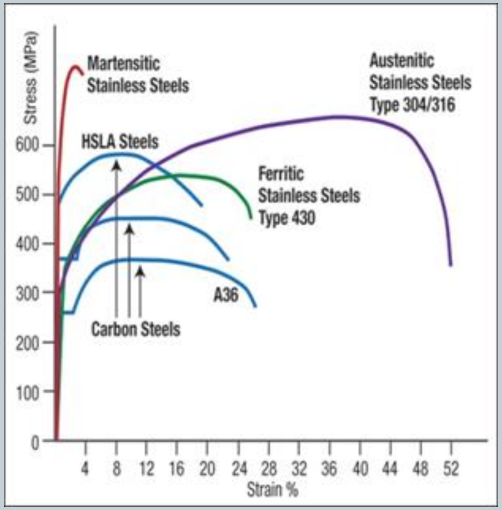
Example # 1 – Research of the impact of the casting technology over the microstructure

The aim of the present study is to apply an approach to study the influence of technological factors on the process of casting of aluminum counterbalancing alloys as a way of managing their quality. For the quality indicator, the DAS microstructure parameter is selected. It represents the distance between the axes of the secondary branches of the dendrites. The parameters of the technological process are controlled in six different volume and location sections. In Fig. 1. Schematic representation of the DAS longitudinal distance. In summary, the minimum values of this parameter are associated with better mechanical properties.

Example # 1 – Research of the impact of the casting technology over the microstructure







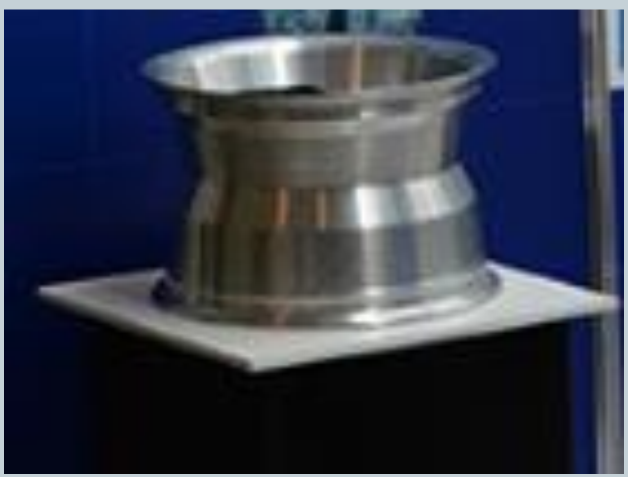
Here are shown the analyzed sections. Microstructure parameter DAS is directly related to the strength properties. A smaller Das is related to a fine grain structure

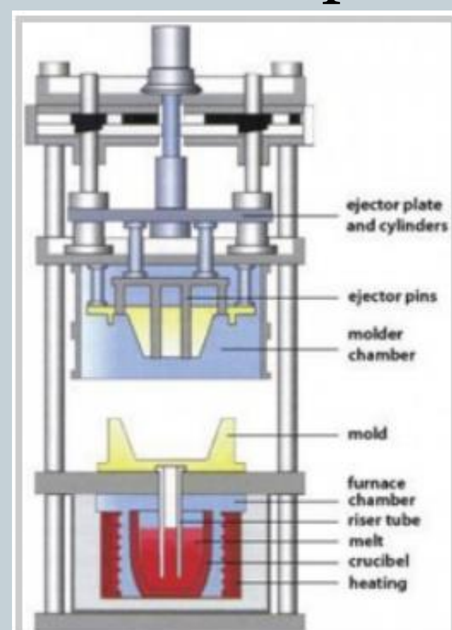
Casting conditions of the tested castings

Technological-parameters mix	Parameter of the technological process			
	Temperature of the liquid metal [°C]	Time of casting [s]	Time between two cycles [s]	Counterpressure [atm]
	X_1	X_2	X_3	X_4
1	760	20	60	3.0
2	760	10	60	3.0
3	760	20	60	4.5
4	750	20	60	1.5
5	750	20	120	1.5
6	760	10	60	4.5
7	730	15	60	3.0
8	730	10	60	3.0
9	730	20	120	3.0
10	730	20	60	3.0
11	700	10	60	4.5
12	750	30	120	4.5
13	750	30	60	1.5
14	750	30	180	4.5
15	730	30	60	4.5
16	730	8	60	4.5
17	700	30	120	4.5
18	700	10	60	4.5

Example # 1 – Research of the impact of the casting technology over the microstructure

The task of the study is to determine the combination of these process parameters providing the minimum DAS parameter values in the six monitored sections. The task thus defined consists in using an interdisciplinary scientific apparatus to solve a problem in order to provide an optimal practical solution.





DAS – values in the examined sections of the casting under various conditions μm

Technological-parameters mix	Section #					
	1	2	3	4	5	6
1	17.8	22.2	20.8	28.6	37.4	21.6
2	15.4	20.2	21.0	33.9	36.0	16.4
3	19.9	21.7	22.5	30.0	35.3	23.0
4	17.9	20.1	20.3	30.0	34.9	18.6
5	19.1	20.0	19.7	28.6	35.3	19.8
6	16.5	27.0	21.4	31.1	35.3	19.7
7	20.1	20.6	20.8	35.4	48.2	17.0
8	18.8	23.7	22.8	33.3	48.3	22.1
9	21.1	22.1	24.2	39.7	49.5	22.2
10	15.2	20.9	23.2	33.5	48.6	18.5
11	16.9	23.1	21.1	31.0	44.6	18.9
12	15.8	20.8	23.7	43.9	46.8	23.9
13	15.5	20.1	22.0	34.8	49.9	19.2
14	15.8	19.8	22.0	35.3	41.3	19.1
15	16.3	21.7	21.2	36.5	41.7	19.3
16	14.5	20.6	20.3	44.0	44.1	20.9
17	15.0	20.3	21.8	34.7	37.7	20.2
18	18.1	20.4	23.1	34.1	44.3	20.1

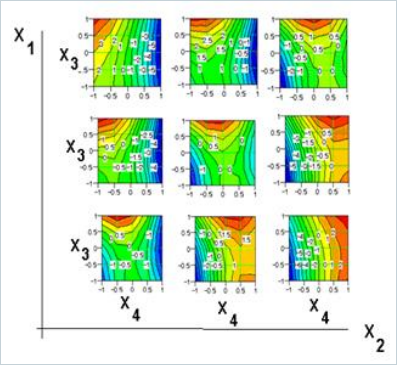
Here we have the values of the 18 different technological modes along the 6 different sections.

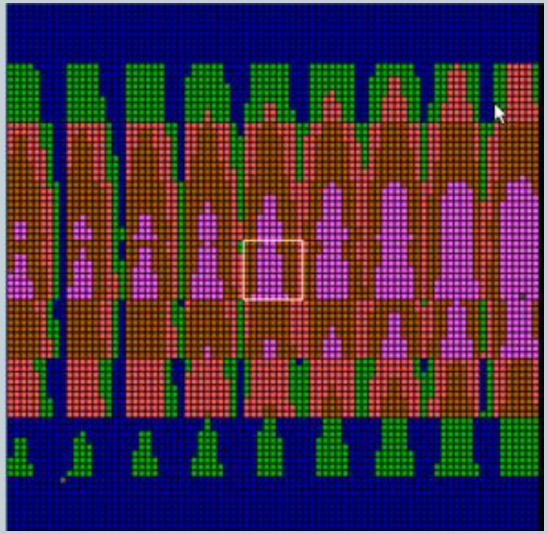
Structure and coefficients of the models describing the microstructure parameter DAS μm

Coefficients of the model	**Section #**					
	DAS 1	DAS 2	DAS 3	DAS 4	DAS 5	DAS 6
Constant term	19.5582	22.0567	23.091	37.9139	46.5593	23.6491
X_1	0.356308	1.23755	-2.12825	-4.15633	-2.26274	-4.08097
X_2	-0.290225	-1.66823	-1.42193	0.383592	1.60002	-4.76152
X_3	-0.244653	0.906765	1.81377	3.2997	-0.837003	5.42704
X_4	0.134641	1.28753	0.562928	2.53965	-0.298139	1.62379
X_1^2	-0.152746	-0.51943	-0.320588	-5.685	-6.48292	-0.659495
$X_1 X_2$	-	-1.31919	2.44311	3.70217	-	5.57892
$X_1 X_3$	0.93663	0.290839	-2.95006	-6.24946	-	-7.70494
$X_1 X_4$	-	-	-	-	-	-
X_2^2	-3.25524	-0.139661	-	-	3.51607	-
$X_2 X_3$	-	-1.7358	-0.734869	1.06929	-	-3.01978
$X_2 X_4$	-	-0.720503	0.687629	-0.205658	-	1.43967
X_3^2	-0.897094	-	-	-	-0.108979	-
$X_3 X_4$	-	-	-	-	-	-
X_4^2	-	-	-	-	-4.73788	-

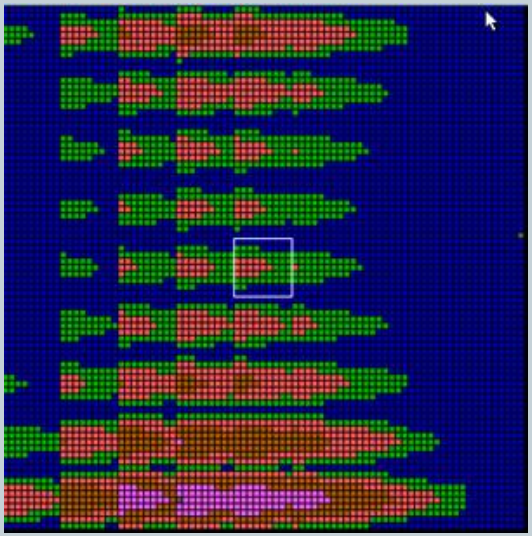
Modeling of the technological process requires the formulation of models describing the relation between the tech. parameter and the tested quantity. Here we have the structure of the six models.

Distribution of DAS values along the sections during varying technological parameters

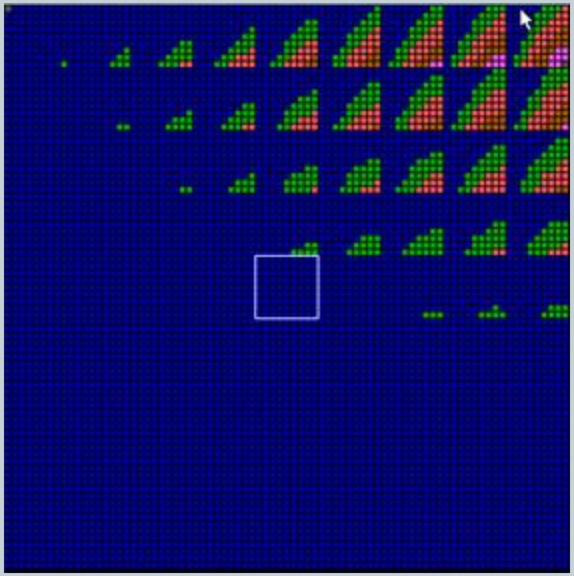




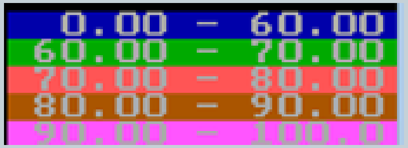
Das1

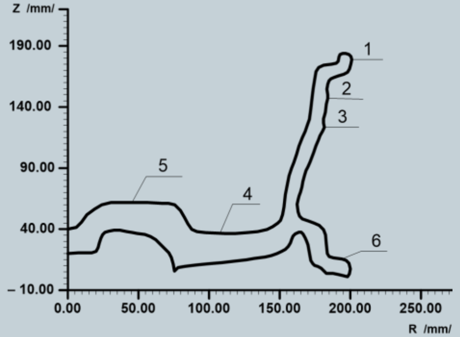


Das5



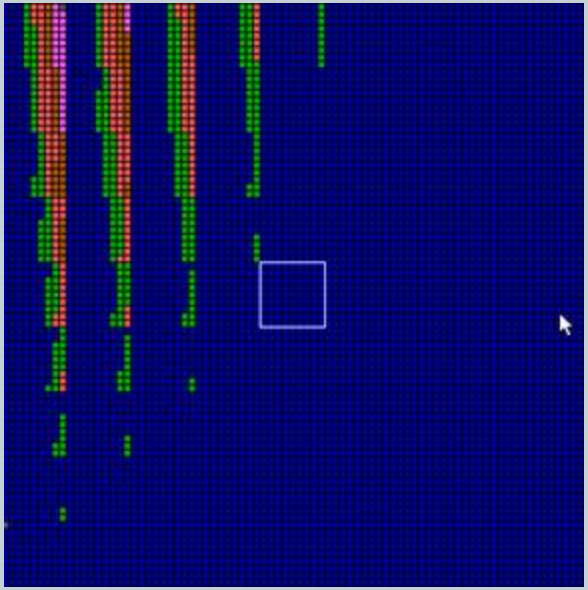
Das2



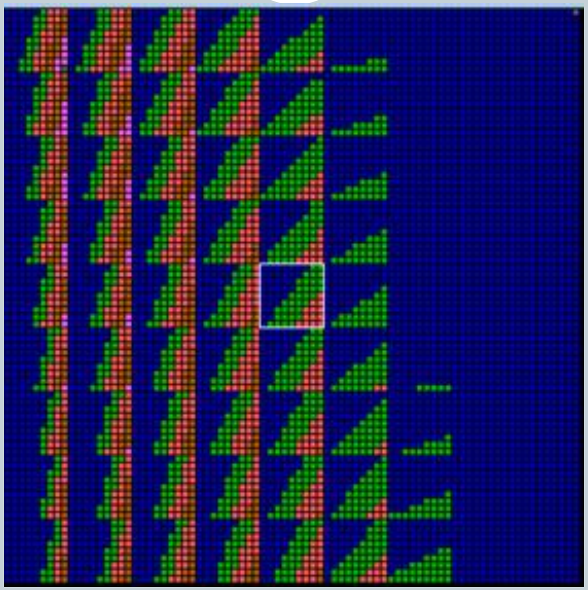


Here Das values are arranged with different colors depending on the four technological parameters. Each panel visualizes Das values of 6,561 combinations of the technological factors.

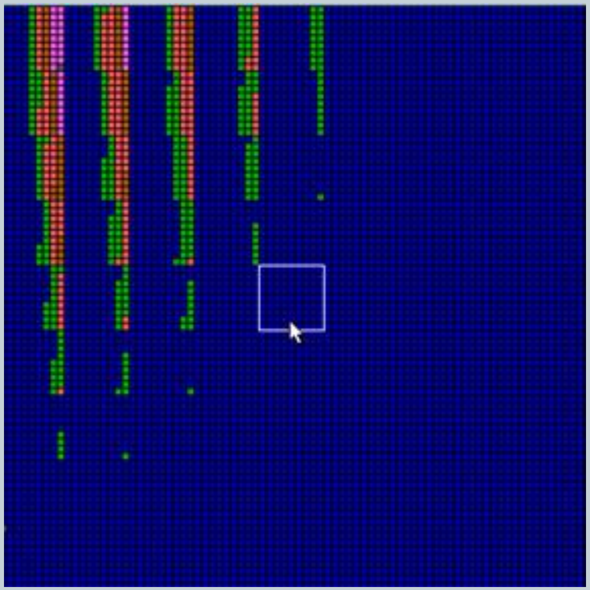
Distribution of DAS values along the sections during varying technological parameters



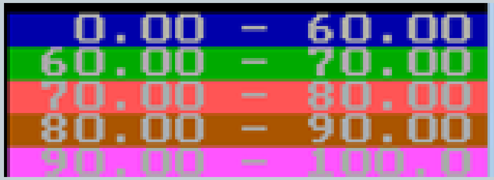
DAS 3

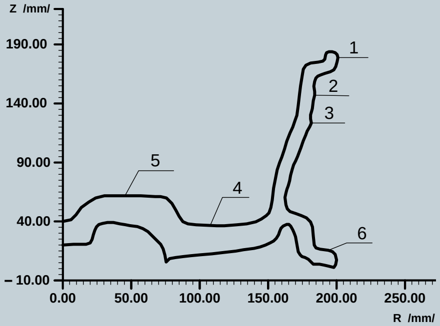


DAS 4



DAS 6





Having Das values in the six sections, the system determines which initial conditions lead to the minimal DAS simultaneously in the six sections.

Optimal technological modes of casting and values of DAS along the sections for the optimal solutions

	Temperature of the liquid metal	Time of casting	Time between two casting cycles	Counterpressure
1st solution	760	8	60	1.5
2nd solution	760	30	180	1.5

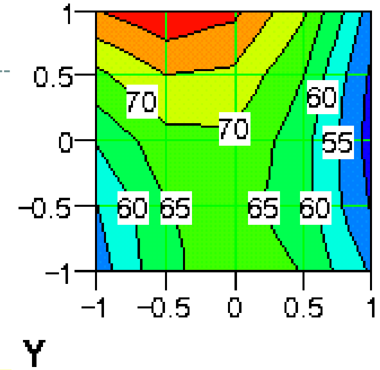
Section	1st solution	2nd solution
DAS1	15	15.8
DAS2	19.9	18.9
DAS3	20.1	18.5
DAS4	25.2	27.9
DAS5	36	37.5
DAS6	17.1	11.3

From the analysis of the two determined solutions it follows that as a complex the second solution is the better one. It is recommended for the final experimentation.

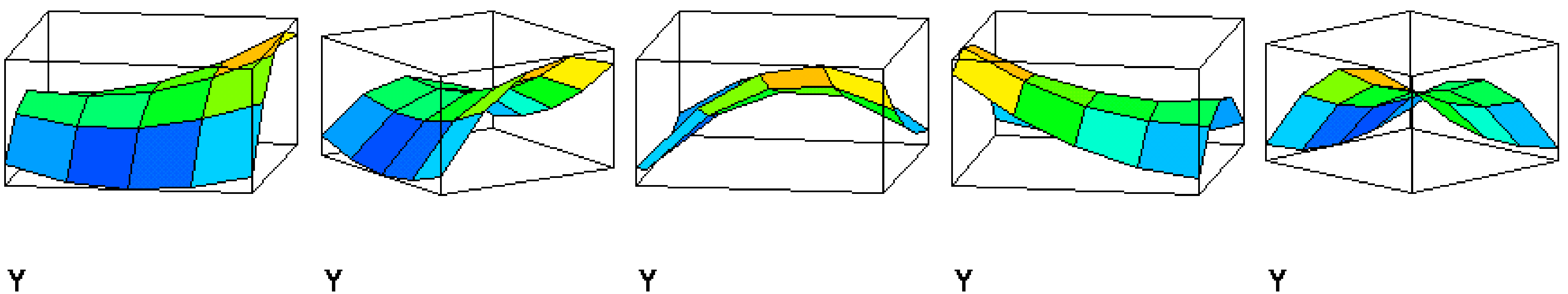
These are the data that is needed to output the models.

- An experiment is conducted with the machine to collect the necessary data.
- Data from the factory worksheets can be used as initial/primary raw information.
- They give the relationship between controlling and controlled quantities.
- A mode of analysis is selected for contour lines at a constant level.
- In this way, the connection between input and output quantities is very easy.
- This is done by fixing / detecting the coordinates.

MADMML Principle of Multi-Parameter Visualization



MADMML® uses its modification of a contour diagram because its three-measurement visualization is independent of the diagram rotation along its vertical axis.



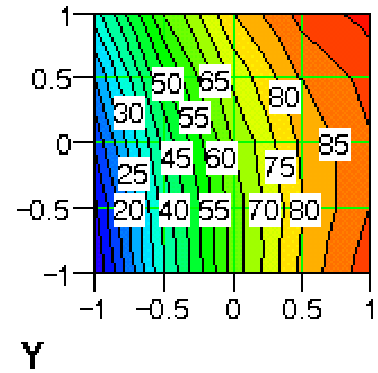
All three-surface diagrams shown above present the contour diagram information seen under different angles. The connection between the value of the quantity examined and the address of the control parameters is difficult and not exact to be indicated (by the three-surface diagrams).

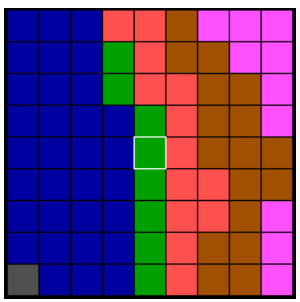
Through a certain step of the Input Parameters, the program has calculated all the values of the test parameter.

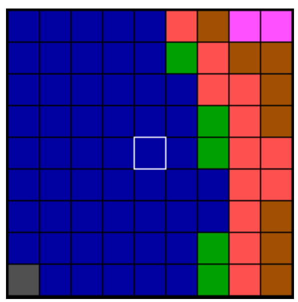
- Through a certain step of the Input Parameters, the program has calculated all the values of the test parameter.
- These values are then colored in a user-defined manner.
- The user, through different moving planes, cuts the response surface.
- The planes move along the ordinate axis and the range between them is colored in a certain color.
- This color is projected onto the appropriate square of the **domain**.
- Thus, the user analyzes the area and sets the maxim**al** and minim**al** values.

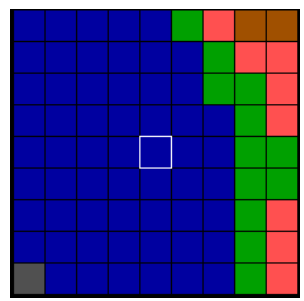
Single-criteria analysis with movable limits

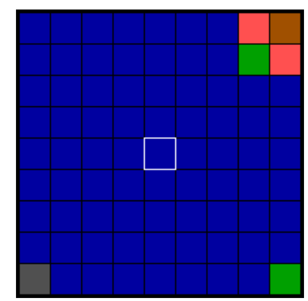
Determining parameters characterized by near values in the space examined with the movement of “cutting” values up towards the maximum.











	Y[1]	0	..	60	%
	Y[2]	60	..	70	%
	Y[3]	70	..	80	%
	Y[4]	80	..	90	%
	Y[5]	90	..	100	%

	Y[1]	0	..	80	%
	Y[2]	80	..	85	%
	Y[3]	85	..	90	%
	Y[4]	90	..	95	%
	Y[5]	95	..	100	%

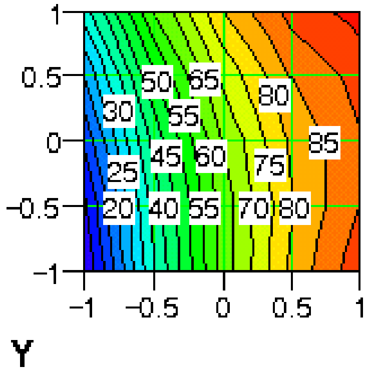
	Y[1]	0	..	85	%
	Y[2]	85	..	90	%
	Y[3]	90	..	95	%
	Y[4]	95	..	99	%
	Y[5]	99	..	100	%

	Y[1]	0	..	92	%
	Y[2]	92	..	94	%
	Y[3]	94	..	96	%
	Y[4]	96	..	98	%
	Y[5]	98	..	100	%

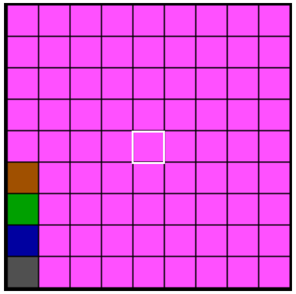
I explain this scheme in detail because it is used for **multifactor** space analysis.

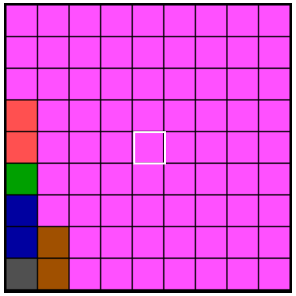
- When defining these values, the software automatically specifies their coordinates.
- Here are the steps to reach the maxim**al** values.
- This is an image of a two-parameter model in which X_1 and X_2 are altered horizontally and vertically from their initial to final values.
- Here is a similar case when looking for minim**al** values.
- Eighty-one 9^2 are the same.

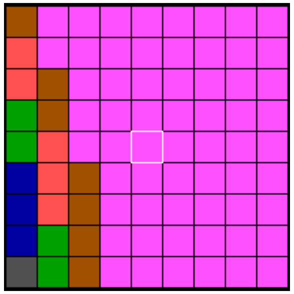
Single-criteria analysis with movable limits

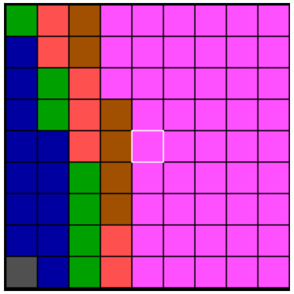


Determining parameters characterized by near values in the space examined with the movement of “cutting” values down towards the minimum.









	Y[1]	0	..	2	%
	Y[2]	2	..	4	%
	Y[3]	4	..	6	%
	Y[4]	6	..	8	%
	Y[5]	8	..	100	%

	Y[1]	0	..	5	%
	Y[2]	5	..	10	%
	Y[3]	10	..	15	%
	Y[4]	15	..	20	%
	Y[5]	20	..	100	%

	Y[1]	0	..	10	%
	Y[2]	10	..	20	%
	Y[3]	20	..	30	%
	Y[4]	30	..	40	%
	Y[5]	40	..	100	%

	Y[1]	0	..	30	%
	Y[2]	30	..	40	%
	Y[3]	40	..	50	%
	Y[4]	50	..	60	%
	Y[5]	60	..	100	%

Coloring is different because each coloration corresponds to a separate iteration.

- This is the basic technique of the analysis, which we will later use not only in the analysis but also in the multicriteria optimization.
- You saw a parameter analysis **with 4 parameters**.
- We have an idea to develop this method up to 10 parameters.
- By now, we only produce models of this magnitude.
- For them, we have a scheme to analyze them with **MathCAD**.
- If **I am assigned/comissioned** during my forthcoming course here, I can pass on **my** experience to **Y**our PhD students with the programs I've come up with.

Multicriteria Aid for Decision Making by Movable Limits

MADMML

Let talk by data using the variety of colors

The following two slides feature the product.

The analysis of the explored dimension is related to its visualization.

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Multicriteria Aid for Decision Making by Movable Limits - MADMML

The offer presented demonstrates the advantages and possibilities of a specialized software product for multi-criteria and multi-parameter aid with making decisions based on the method of movable limitations*. This method has been considerably applied with developing a number of technology processes in the machine manufacturing production in order to determine the combinations of control factors satisfying the requirements given beforehand by a decision maker (DM).*

MADMML Application Domain

MADML presents an immediate ("ad hoc") decision-making procedure, which reduces the admissible set to reach trade-off solutions. Since the experimental approach does not use information about the mechanism of the running phenomena, MADMML is a universal system to analyze multi factory spaces. One and the same methods of processing the values experimentally determined are possible to be applied to a lot of various objects: chemical; metallurgical; biotechnological; ecological, etc.

When viewing many parameters, for example, 4, two of the variables are fixed.

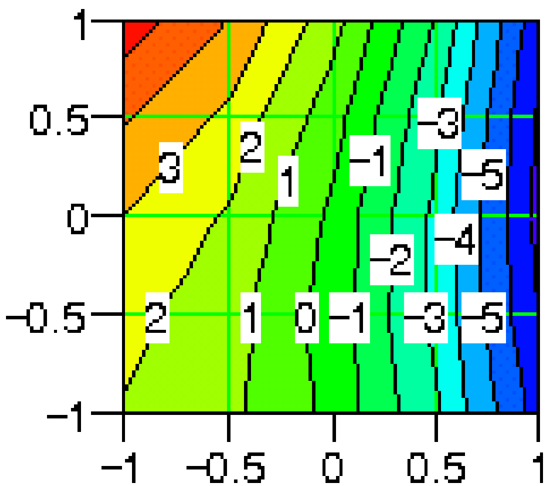
These variables change globally in the **domain**, and the other two in each local quadrant.

This image is an **ordered** arrangement of combinations of **the** input factors.

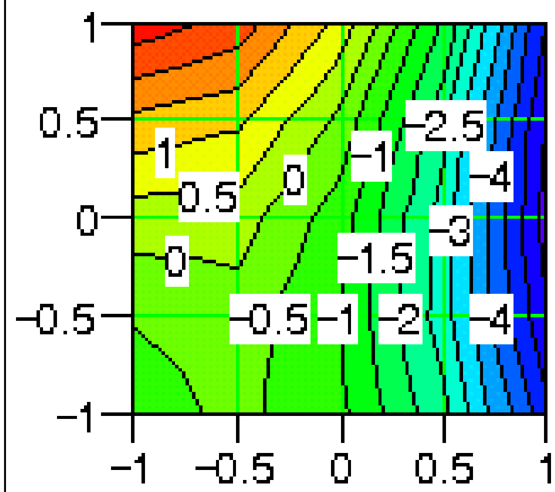
The value of the sample is [coded by] the appropriate color.

Disadvantages of Software Available for Multi-Parameter Visualization

X_1=-1
X_2=-1



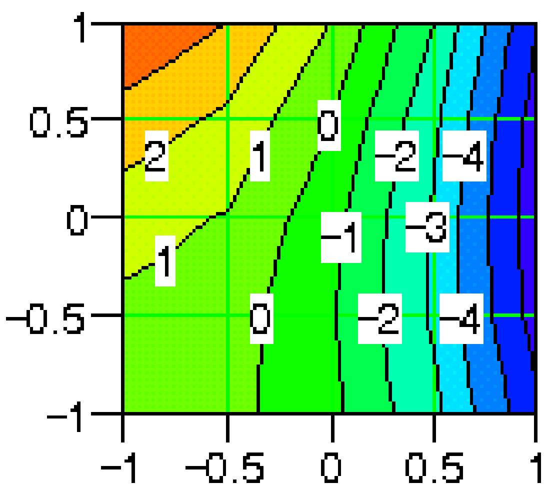
Y = f (X_3, X_4)



Y = f (X_3, X_4)

X_1=-1
X_2=-0

X_1=-1
X_2=-0.5



Y = f (X_3, X_4)

If parameter X_3 changes along the ordinate and X_4 changes along the abscissa the disadvantages of the software available consist of:

- a considerable number of drawing contour diagram with parameters X_1 and X_2 fixed;
- the accuracy of the analysis depends on the discretization along parameters fixed;
- the drawing contour diagrams of the quantity examined are not arranged one towards another according to their values.

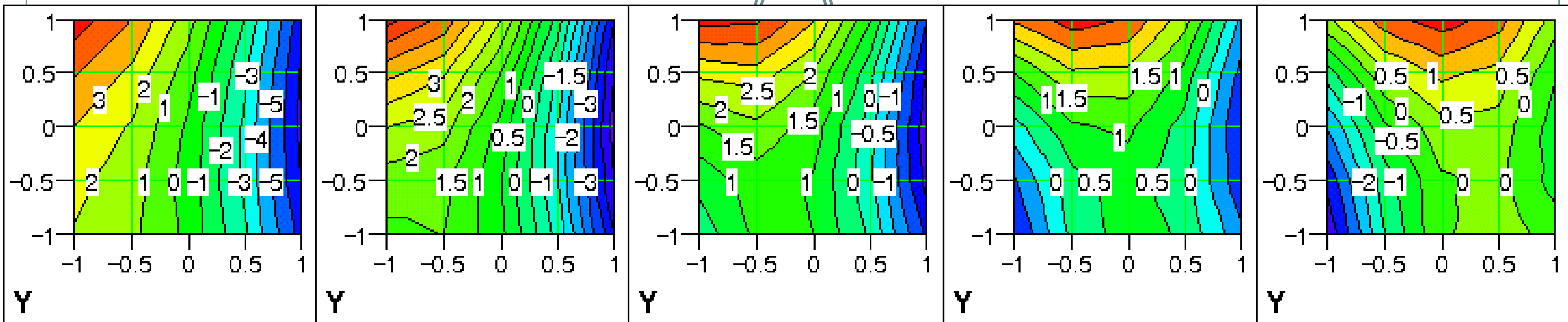
This arrangement in a certain sense is a layout of diagrams with lines at a constant level.

They are arranged in the same way as the coordinate system is oriented.

From the beginning of the coordinate system, the starting values are changed to X_1 and X_2 by a certain step.

Disadvantages of Software Available for Multi-Parameter Visualization

X_2=-1



X_1=-1 X_1=-0.5 X_1=0 X_1=0.5 X_1=1

a_1= 0.4325	**a_6=-1.196**	**a_{11}= 2.15432**
a_2=-0.008248	**a_7=-0.259**	**a_{12}= 1.01693**
a_3=-0.228915	**a_8= 2.9977**	**a_{13}=-1.95535**
a_4= 0.033695	**a_9= 0.15847**	**a_{14}=-0.944752**
a_5= 0.003165	**a_{10}= 0.61596**	**a_{15}= 0.744787**

To prove the statement presented above the following example can be given. If discretization is chosen along X_1 with points [-1, -0.5, 0, 0.5, 1] with X_2 =-1 fixed and it is accepted that X_3 changes along the ordinate and X_4 changes along the abscissa then:

- a considerable number of diagram patterns can be watched with parameter X_2 fixed;
- the accuracy of the analysis depends on the very discretization of the parameter fixed;
- the contour diagrams of quantity Y examined are not arranged one towards another according to their values.

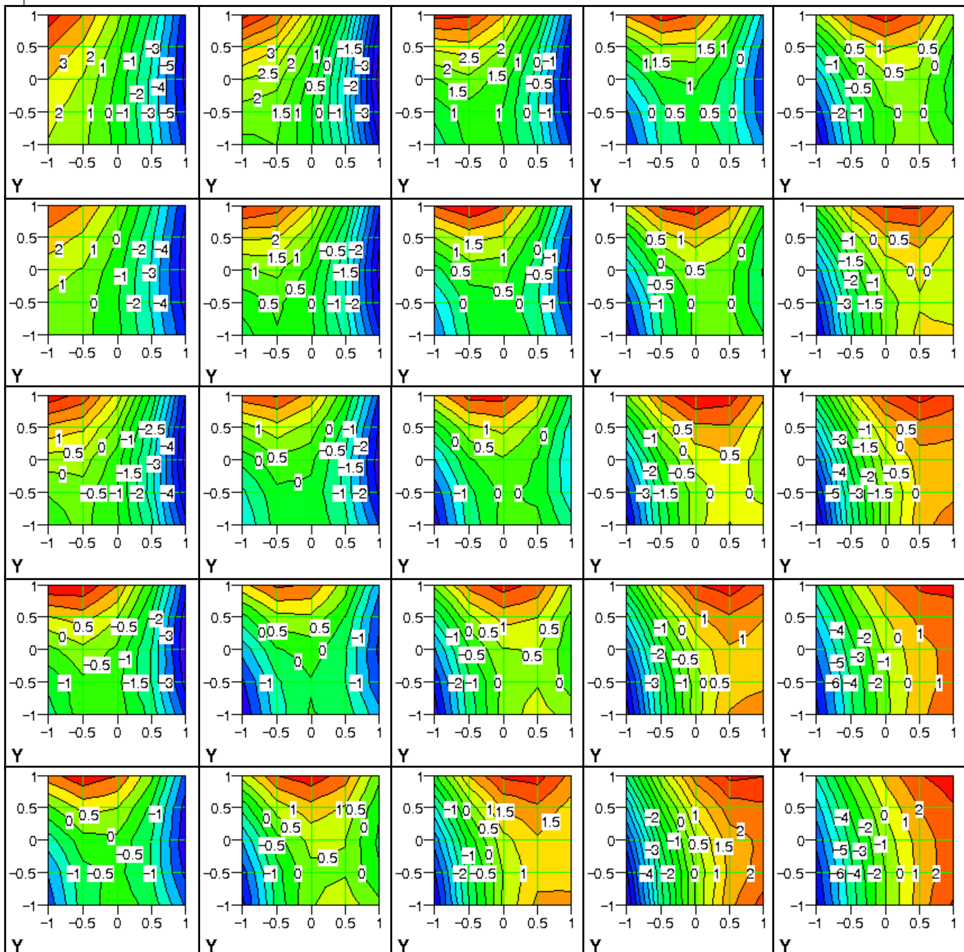
$$\mathbf{Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+}$$
$$\mathbf{+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2}$$

On this slide, the contour diagrams are displayed on changing X_3 and X_4 and X_1, and fixed X_2.

This way, You represent the 5D /4 + 1/ space.

In summary, the following can be stated.

Disadvantages of Software Available for Multi-Parameter Visualization



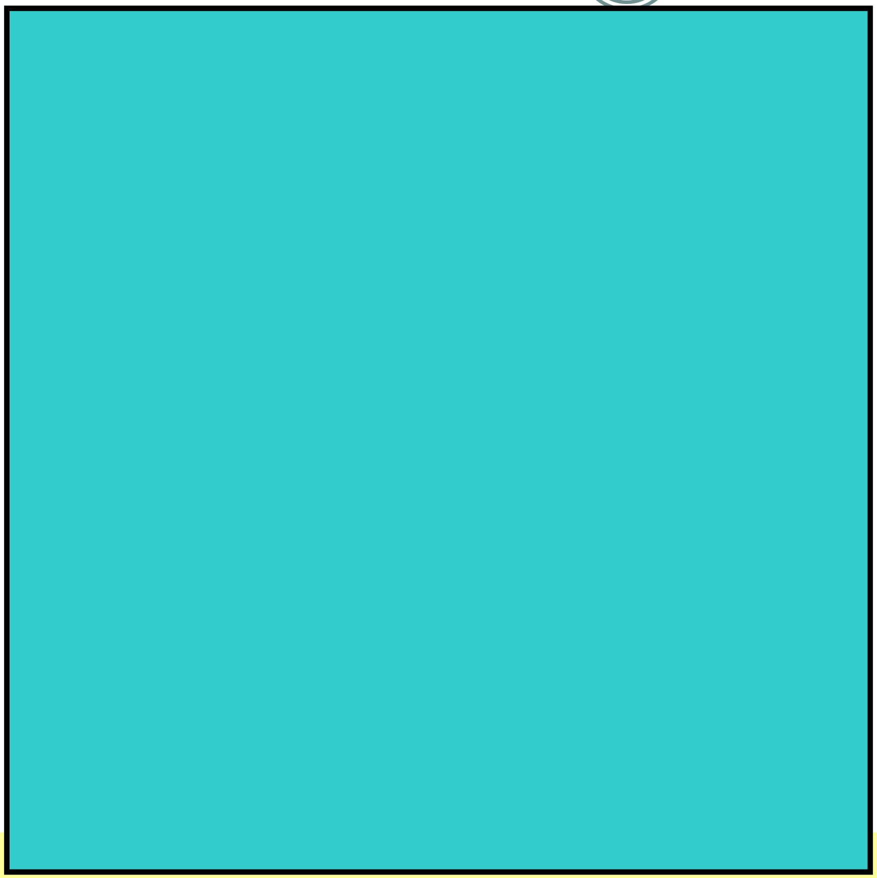
It is necessary to examine 25 contour diagrams like the ones pointed to the left where X_1 and X_2 vary in order to orient the Decision-Maker in the discretization given along X_1, X_2, X_3 and X_4 with a set of discrete points [-1, -0.5, 0, 0.5, 1].

In that case there is only one problem and it concerns the contour diagrams which are not arranged one towards another.

$a_1= 0.4325$	$a_6=-1.196$	$a_{11}= 2.15432$
$a_2=-0.008248$	$a_7=-0.259$	$a_{12}= 1.01693$
$a_3=-0.228915$	$a_8= 2.9977$	$a_{13}=-1.95535$
$a_4= 0.033695$	$a_9= 0.15847$	$a_{14}=-0.944752$
$a_5= 0.003165$	$a_{10}= 0.61596$	$a_{15}= 0.744787$

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+$$
$$+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$

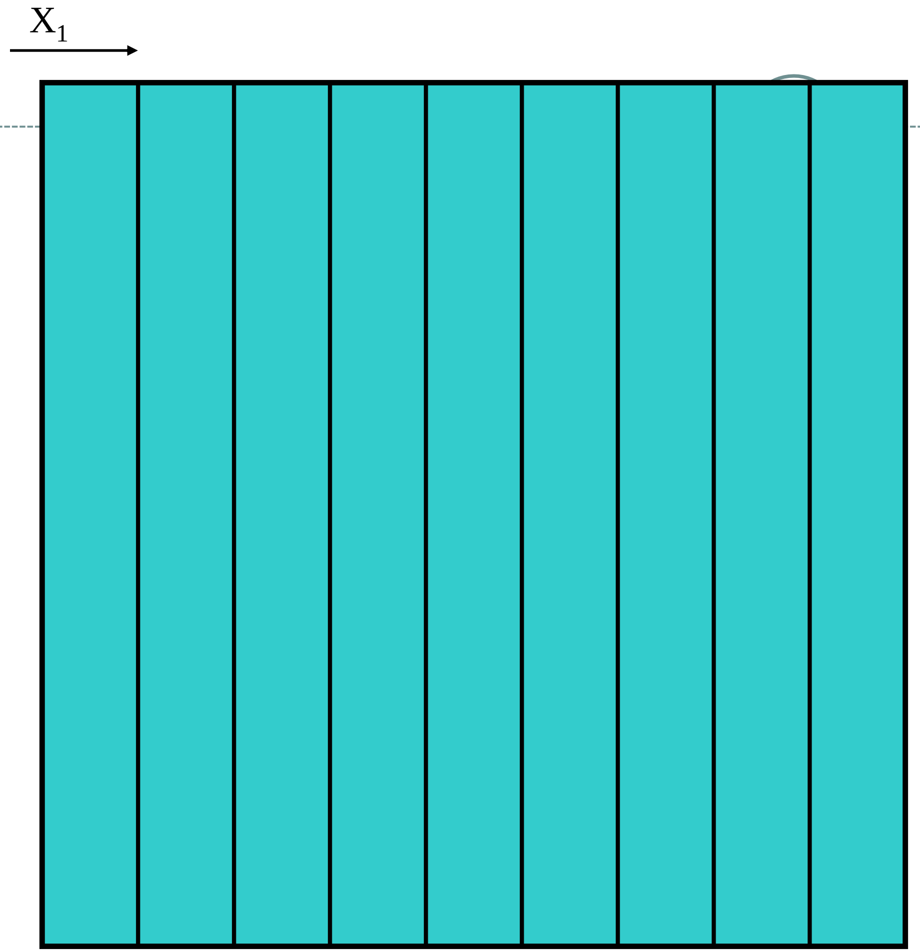
MADMML Principle of Multi-Parameter Visualization



STEP I

-Representation of the area where multi-parameter visualization will be carried out

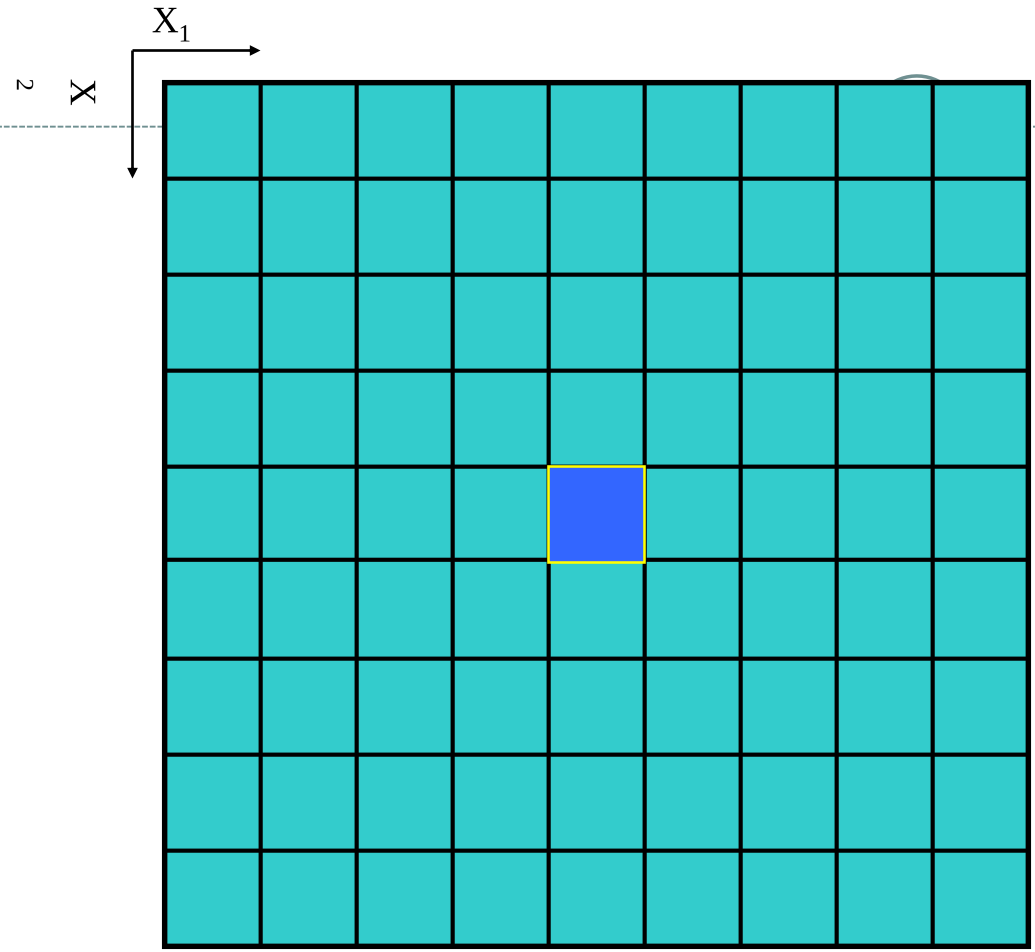
MADMML Principle of Multi-Parameter Visualization

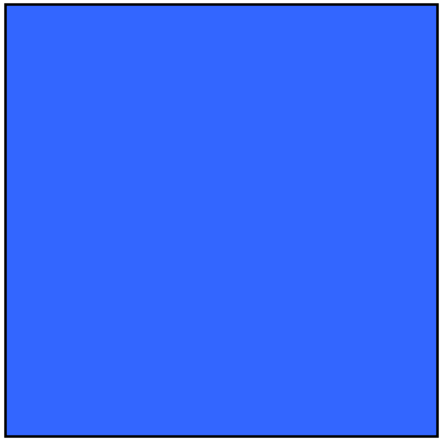


STEP II

- discretisation of the field in relation to parameter X_1 with given limitations and a step of change.

MADMML® Principle of Multi-Parameter Visualization

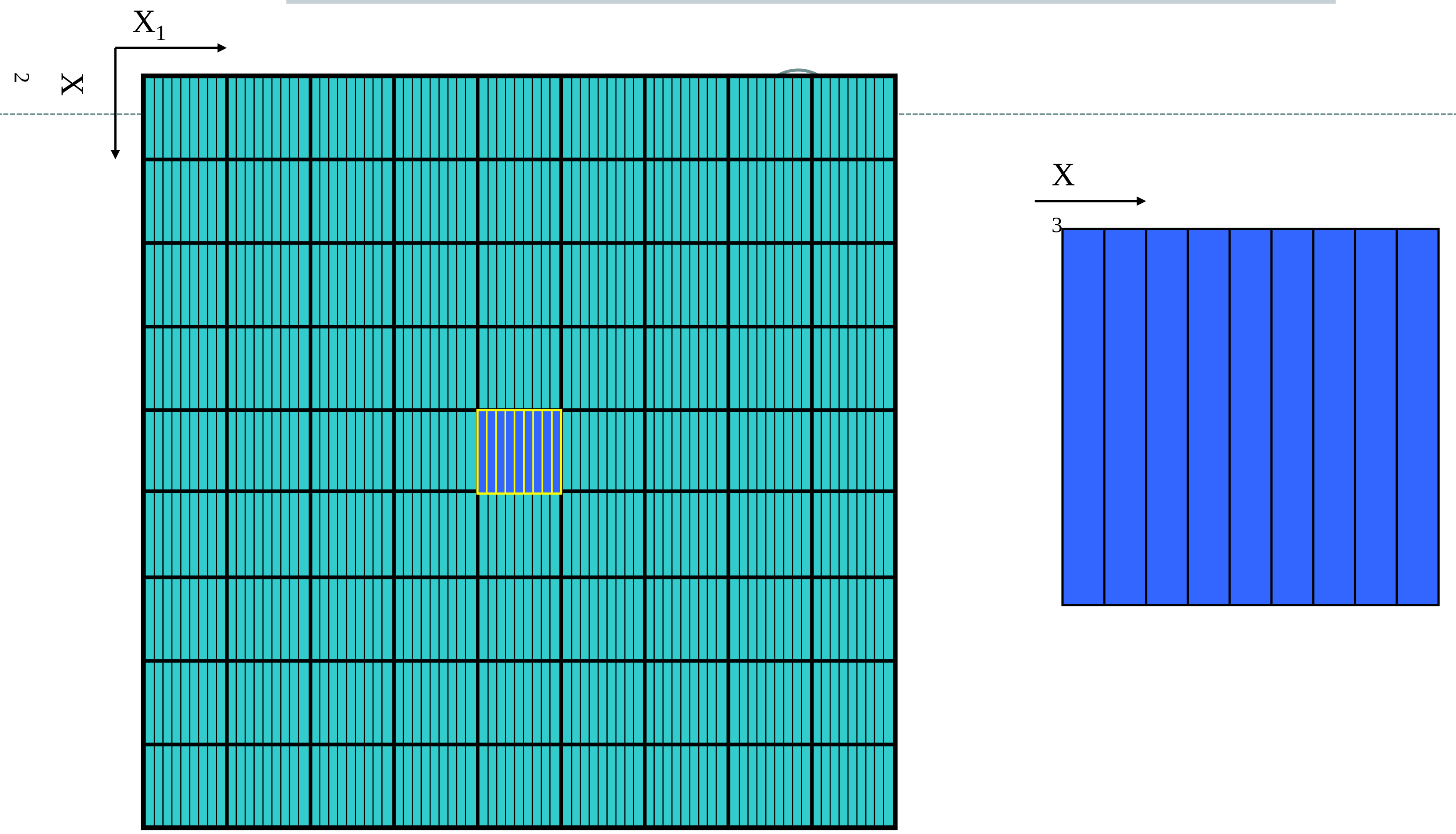




STEP III

- discretisation of the field in relation to parameter X_2 with given limitations and a step of change as well as formation of forming an instrument to keep up with the changes of X_1 and X_2.

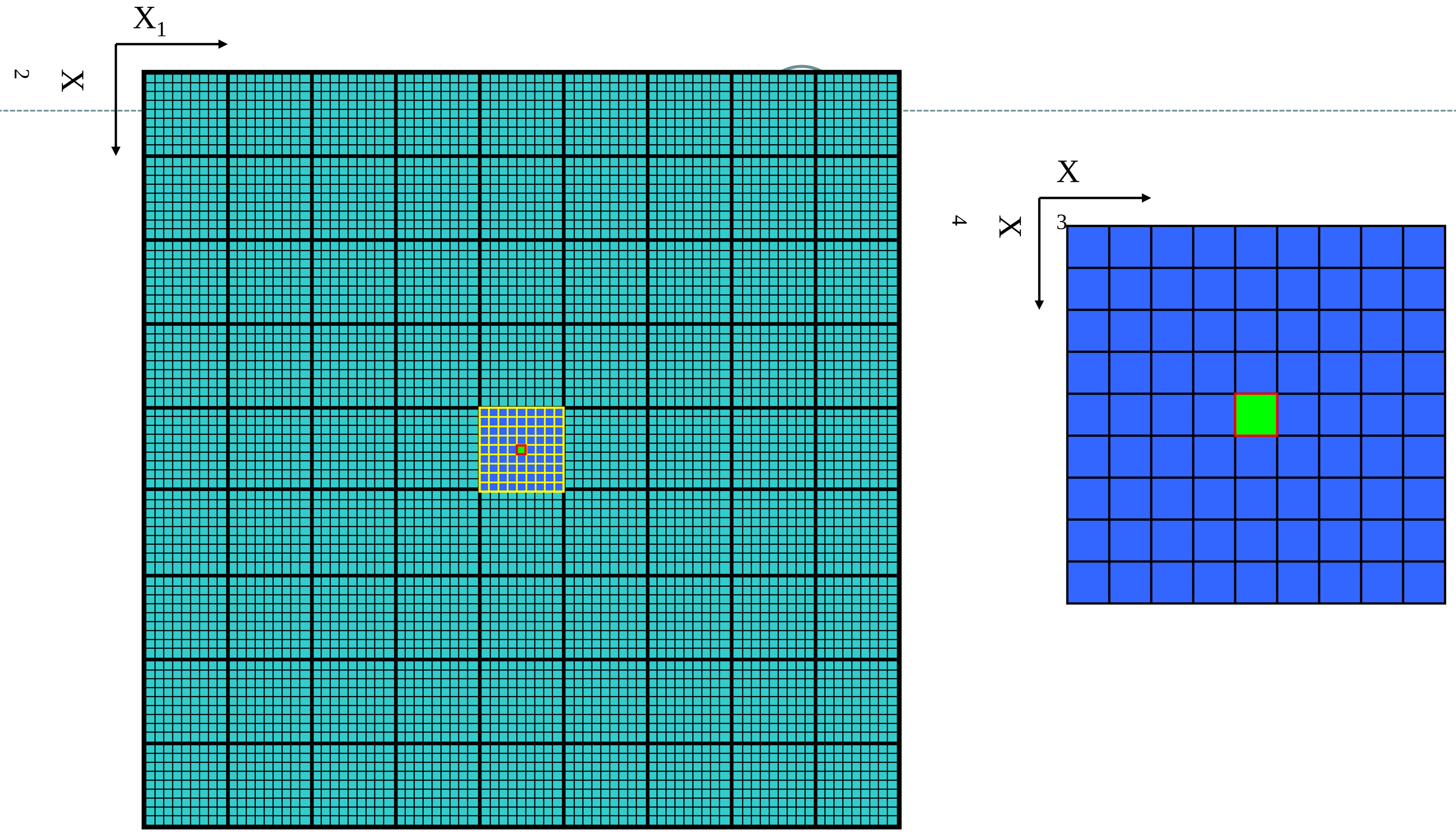
MADMML Principle of Multi-Parameter Visualization



STEP IV

- discretisation of the field in relation to parameter X_3 with given limitations and a step of change.

MADMML® Principle of Multi-Parameter Visualization



STEP V

-discretisation of the field in relation to parameter X_4 with given limitations and a step of change as well as input of a global address determining system according to all variables necessary for visualization of the parameter model.

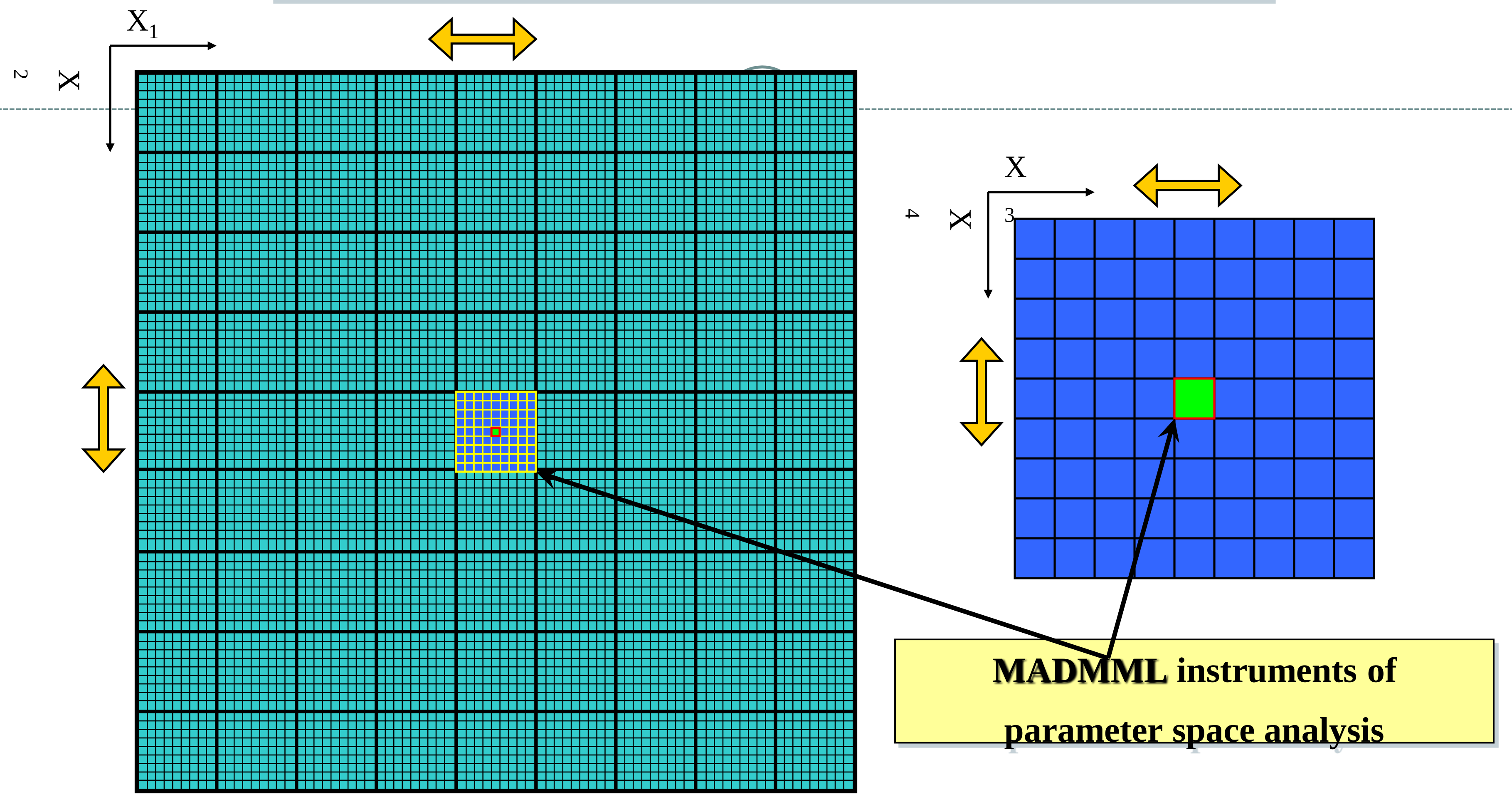
This is the entire **domain** in which all the variables are changed, in the case 4.

In this space, sampling is performed on X_1, X_2, X_3 and X_4.

In the **domain**, a **zoom tool** is embedded, which includes a local diagram.

It has fixed X_1 and X_2.

MADMML Principle of Multi-Parameter Visualization



The process of multi-factor analysis is realized through MADMML instruments in the spaces of parameters. With the indicated discretisation, 9^4=6561conbination among the indicated four variables are simultaneously analyzed .

This magnifier is projected to the right, where is the marker that determines the coordinates of the input factors and the value of the magnitude being examined.

The marker is embedded in the big zoom.

It is displayed when global parameters are fixed.

The tag takes into account all the parameters and the research quantity.

Here’s **the** analysis shown on the next three slides.

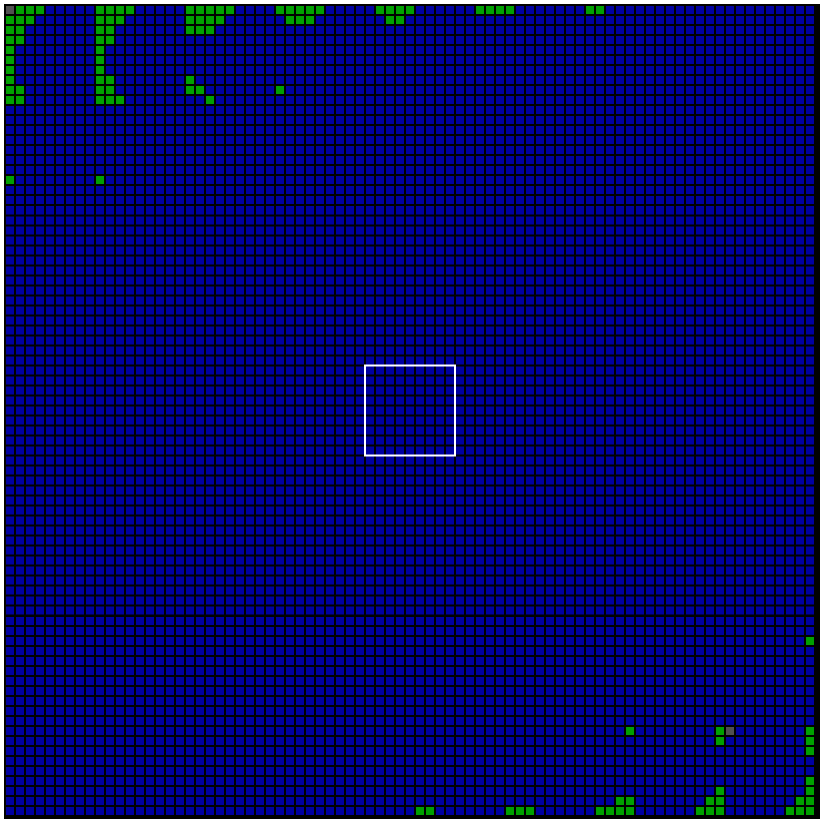
For the regression model, these coefficients are quoted /in green/ all values of the studied quantity above 90%.

As impressed, the maximal values are in two opposite regions of the area.

These two opposite regions are characterized by different energy and material resources of the input factors.

We make a compromise with the value of the magnitude we investigate and we choose that value that is most useful.

Single-criteria analysis with movable limits



The method helps in determining the direction of searching. The zones colored in green show areas where the values of the quantity examined are over 90%

$a_1= 0.4325$ $a_6=-1.196$ $a_{11}= 2.15432$

$a_2=-0.008248$ $a_7=-0.259$ $a_{12}= 1.01693$

$a_3=-0.228915$ $a_8= 2.9977$ $a_{13}=-1.95535$

$a_4= 0.033695$ $a_9= 0.15847$ $a_{14}=-0.944752$

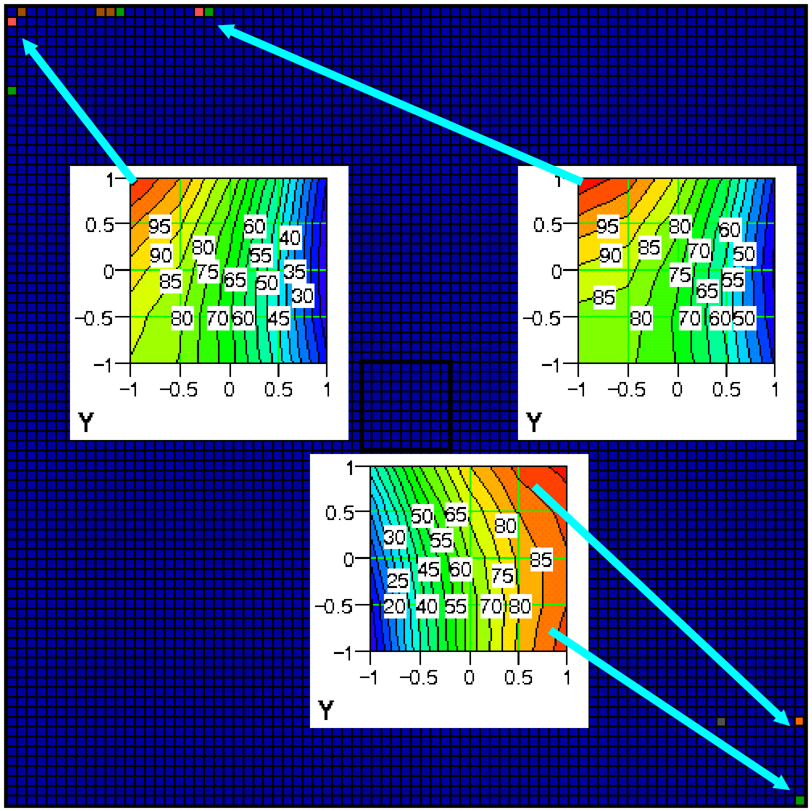
$a_5= 0.003165$ $a_{10}= 0.61596$ $a_{15}= 0.744787$

	Y[1]	0	..	90	%
	Y[2]	90	..	100	%

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+ +a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$

The movement analysis via the moving planes determines the maximal values of the **explored** quantity.

Single-criteria analysis with movable limits



Localizing the area and determining certain solutions. Representing the solutions by appropriate contour diagrams

(dark blue)	Y[1] between 0 .. 96 %
(green)	Y[2] between 96 .. 97 %
(red)	Y[3] between 97 .. 98 %
(brown)	Y[4] between 98 .. 99 %
(magenta)	Y[5] between 99 .. 100 %

All the values of the test parameters corresponding to a precisely defined percentage interval can be determined in the space of the technological parameters.

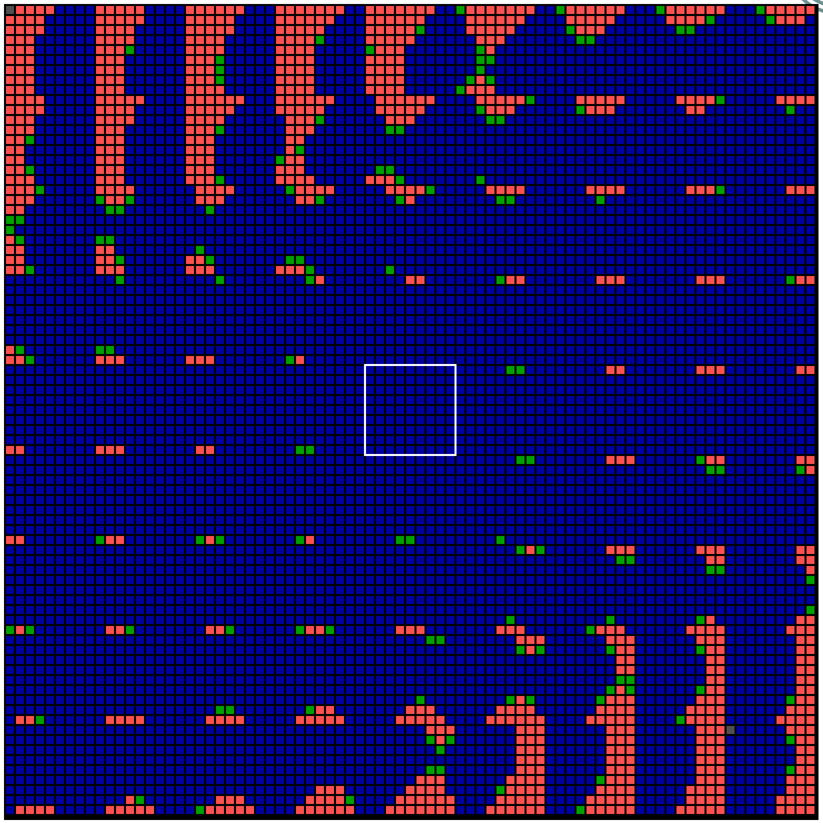
This is done here.

All combinations of input parameters are marked green, with the test parameter being between 80-81%.

This interval may narrow or expand.

Through this example, it is also possible to search for energy values.

Single-criteria analysis with movable limits



Determining the states where the quality parameter contains an exactly determined value. The value of the quantity examined in all areas colored in green are within the interval between 80% and 81%.

$a_1 = 0.4325$ $a_6 = -1.196$ $a_{11} = 2.15432$

$a_2 = -0.008248$ $a_7 = -0.259$ $a_{12} = 1.01693$

$a_3 = -0.228915$ $a_8 = 2.9977$ $a_{13} = -1.95535$

$a_4 = 0.033695$ $a_9 = 0.15847$ $a_{14} = -0.944752$

$a_5 = 0.003165$ $a_{10} = 0.61596$ $a_{15} = 0.744787$

(blue)	Y[1]	0	..	80	%
(green)	Y[2]	80	..	81	%
(red)	Y[3]	81	..	100	%

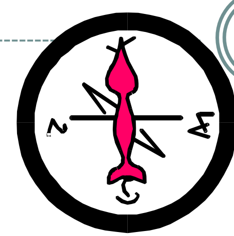
$$Y(x_1, x_2, x_3, x_4) = a_1 + a_2.x_1 + a_3.x_2 + a_4.x_3 + a_5.x_4 + a_6.x_1^2 + a_7.x_1.x_2 + a_8.x_1.x_3 + a_9.x_1.x_4 + a_{10}.x_2^2 + a_{11}.x_2.x_3 + a_{12}.x_2.x_4 + a_{13}.x_3^2 + a_{14}.x_3.x_4 + a_{15}.x_4^2$$

The approach so defined is dynamically illustrated by the Compass Device of MADMML

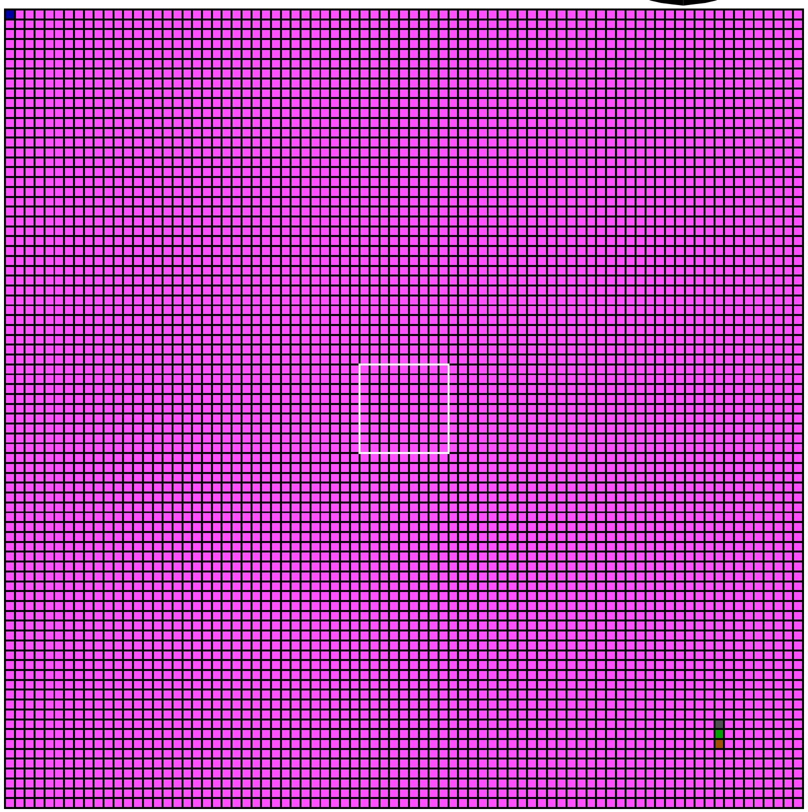
Following is the visualization of the same model in 11 steps in the motion of the planes from the minimum to the maximum

The movable limits possibilities with the analysis only of one of the criteria is revealed by a number of slides following below:

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+$$
$$+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$



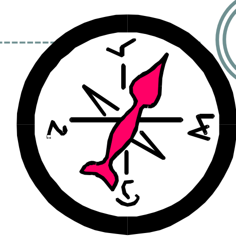
- ***<u>Стъпка - 0</u>***

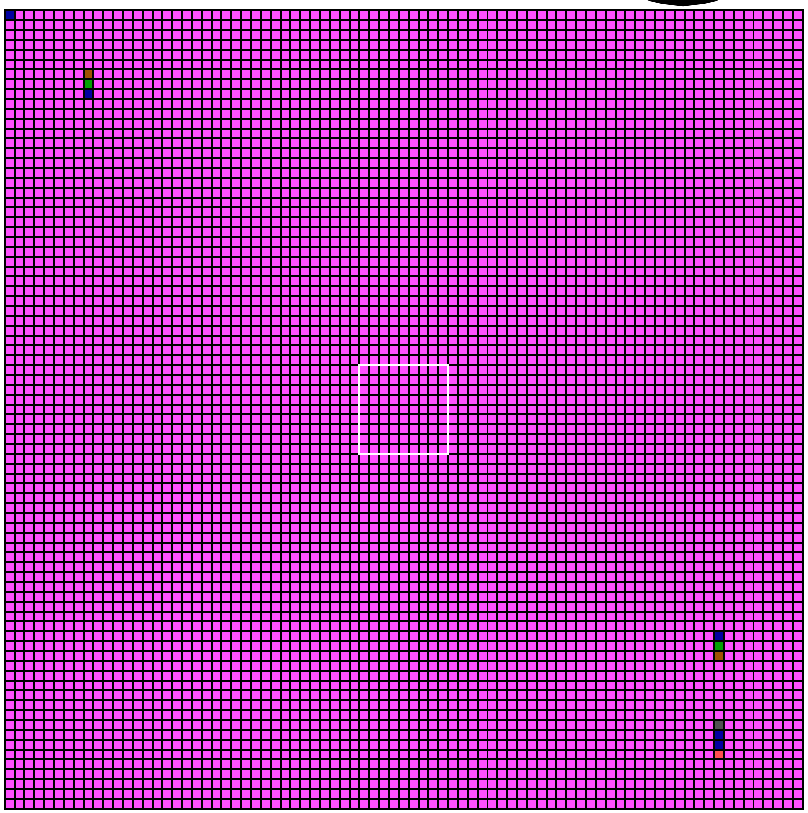


Y[1]	между	0	..	1	%
Y[2]	между	1	..	2	%
Y[3]	между	2	..	3	%
Y[4]	между	3	..	4	%
Y[5]	между	4	..	100	%

a_1= 0.4325	a_6=-1.196	a_{11}= 2.15432
a_2=-0.008248	a_7=-0.259	a_{12}= 1.01693
a_3=-0.228915	a_8= 2.9977	a_{13}=-1.95535
a_4= 0.033695	a_9= 0.15847	a_{14}=-0.944752
a_5= 0.003165	a_{10}= 0.61596	a_{15}= 0.744787

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+$$
$$+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$

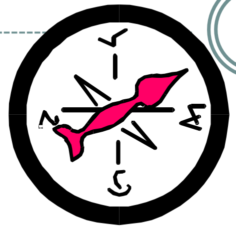


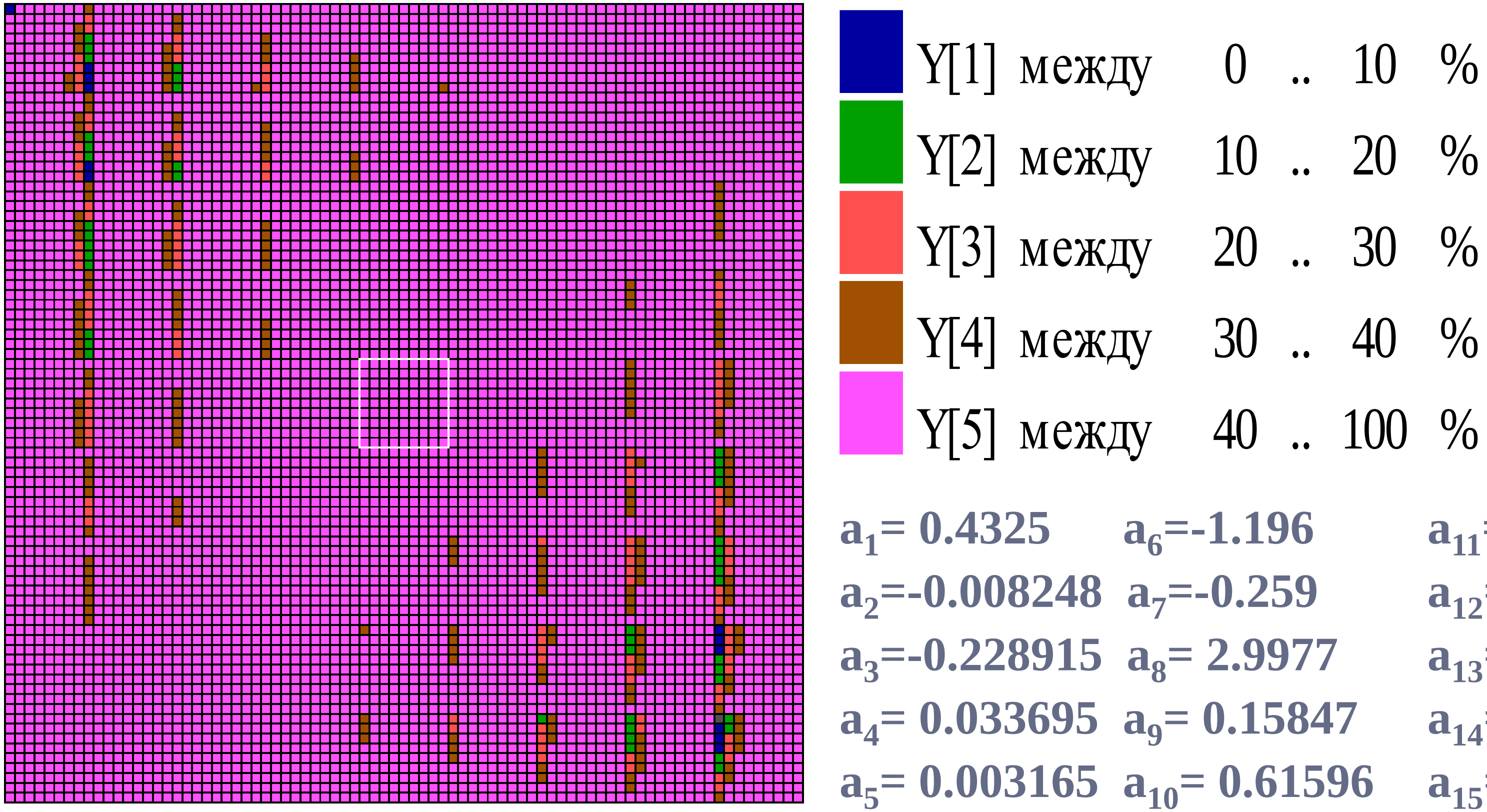


Y[1]	между	0	..	5	%
Y[2]	между	5	..	6	%
Y[3]	между	6	..	7	%
Y[4]	между	7	..	8	%
Y[5]	между	8	..	100	%

a_1= 0.4325	a_6=-1.196	a_{11}= 2.15432
a_2=-0.008248	a_7=-0.259	a_{12}= 1.01693
a_3=-0.228915	a_8= 2.9977	a_{13}=-1.95535
a_4= 0.033695	a_9= 0.15847	a_{14}=-0.944752
a_5= 0.003165	a_{10}= 0.61596	a_{15}= 0.744787

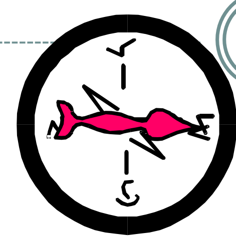
$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+$$
$$+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$

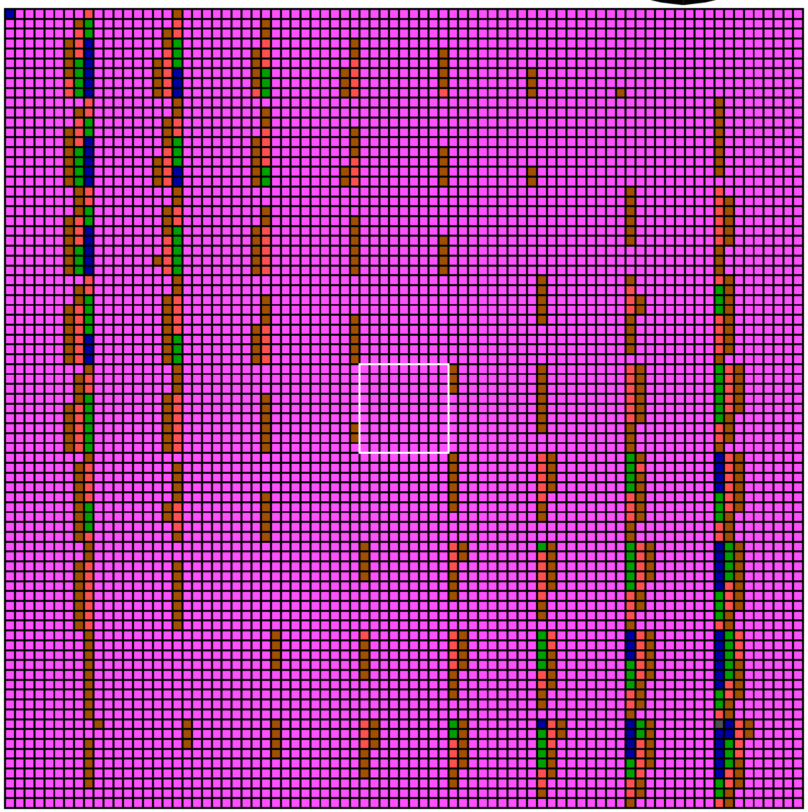




a_1= 0.4325 a_6=-1.196 a_{11}= 2.15432
a_2=-0.008248 a_7=-0.259 a_{12}= 1.01693
a_3=-0.228915 a_8= 2.9977 a_{13}=-1.95535
a_4= 0.033695 a_9= 0.15847 a_{14}=-0.944752
a_5= 0.003165 a_{10}= 0.61596 a_{15}= 0.744787

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+ \\ +a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$





Y[1] между 0 .. 20 %

Y[2] между 20 .. 30 %

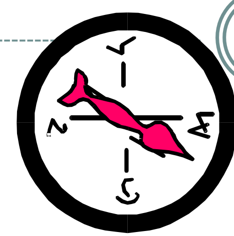
Y[3] между 30 .. 40 %

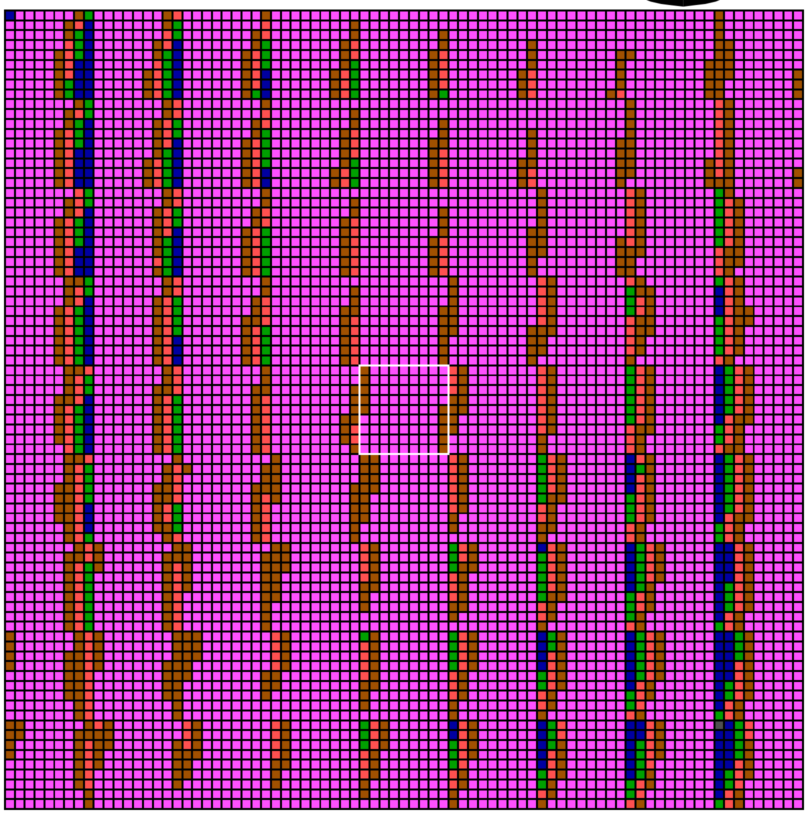
Y[4] между 40 .. 50 %

Y[5] между 50 .. 100 %

a_1= 0.4325	a_6=-1.196	a_{11}= 2.15432
a_2=-0.008248	a_7=-0.259	a_{12}= 1.01693
a_3=-0.228915	a_8= 2.9977	a_{13}=-1.95535
a_4= 0.033695	a_9= 0.15847	a_{14}=-0.944752
a_5= 0.003165	a_{10}= 0.61596	a_{15}= 0.744787

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+$$
$$+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$





Y[1] между 0 .. 30 %

Y[2] между 30 .. 40 %

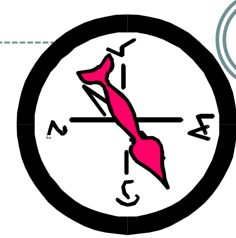
Y[3] между 40 .. 50 %

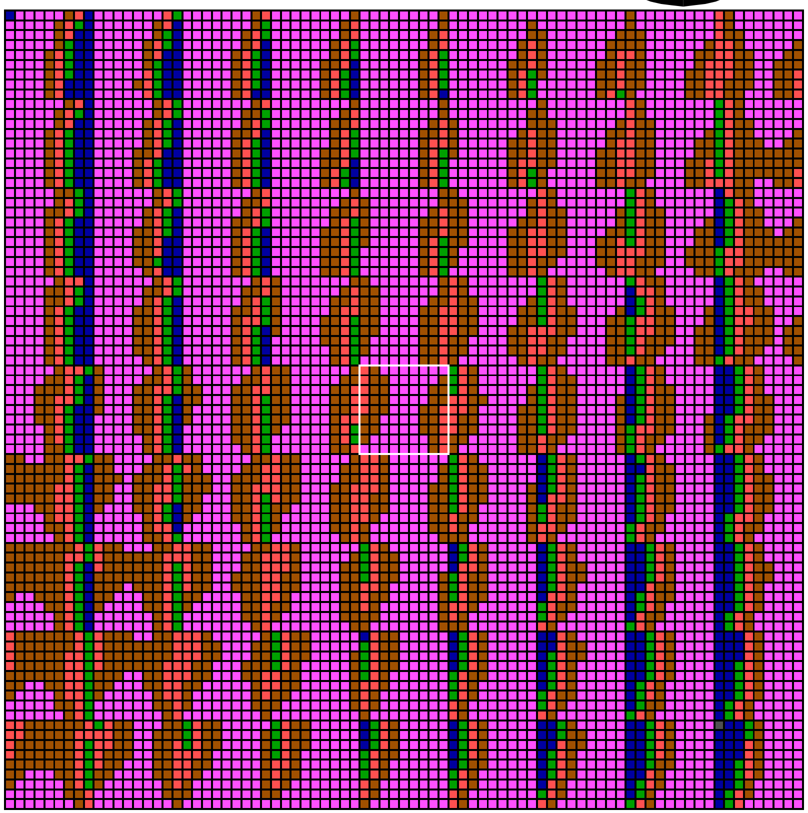
Y[4] между 50 .. 60 %

Y[5] между 60 .. 100 %

a_1= 0.4325	a_6=-1.196	a_{11}= 2.15432
a_2=-0.008248	a_7=-0.259	a_{12}= 1.01693
a_3=-0.228915	a_8= 2.9977	a_{13}=-1.95535
a_4= 0.033695	a_9= 0.15847	a_{14}=-0.944752
a_5= 0.003165	a_{10}= 0.61596	a_{15}= 0.744787

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+$$
$$+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$





Y[1] между 0 .. 40 %

Y[2] между 40 .. 50 %

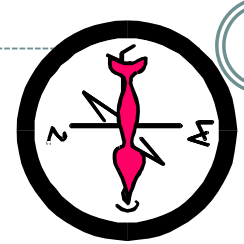
Y[3] между 50 .. 60 %

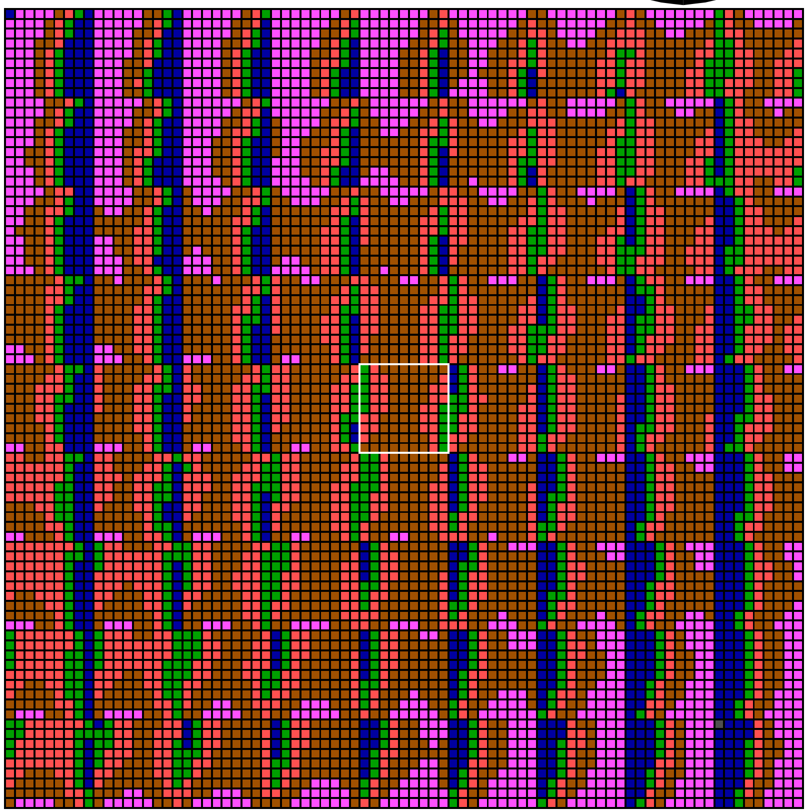
Y[4] между 60 .. 70 %

Y[5] между 70 .. 100 %

a_1= 0.4325	a_6=-1.196	a_{11}= 2.15432
a_2=-0.008248	a_7=-0.259	a_{12}= 1.01693
a_3=-0.228915	a_8= 2.9977	a_{13}=-1.95535
a_4= 0.033695	a_9= 0.15847	a_{14}=-0.944752
a_5= 0.003165	a_{10}= 0.61596	a_{15}= 0.744787

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+$$
$$+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$





Y[1] между 0 .. 50 %

Y[2] между 50 .. 60 %

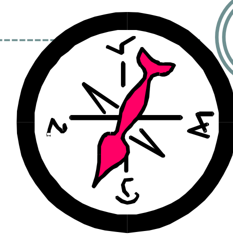
Y[3] между 60 .. 70 %

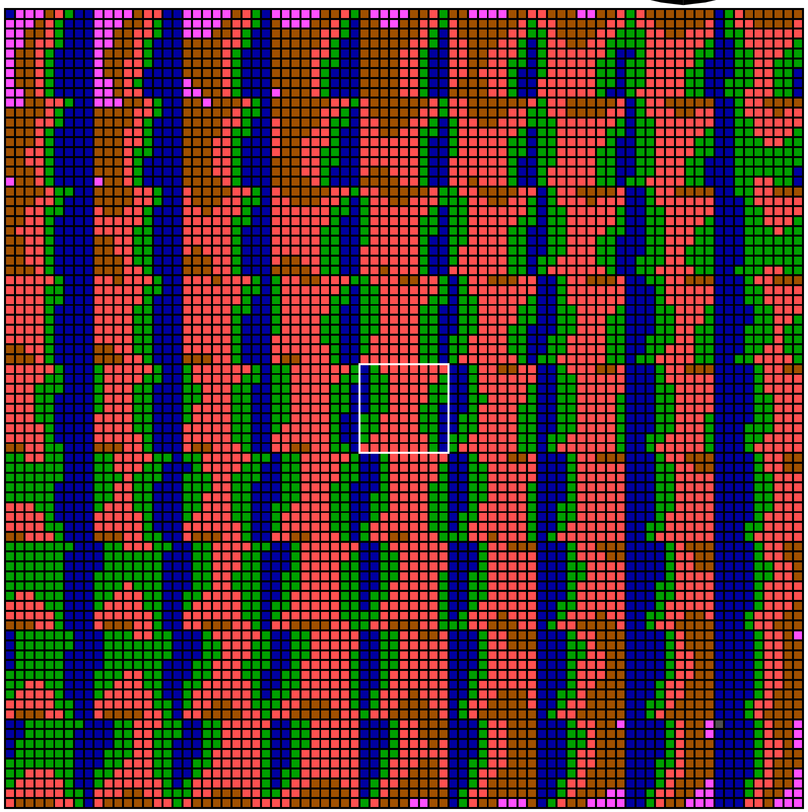
Y[4] между 70 .. 80 %

Y[5] между 80 .. 100 %

a_1= 0.4325	a_6=-1.196	a_{11}= 2.15432
a_2=-0.008248	a_7=-0.259	a_{12}= 1.01693
a_3=-0.228915	a_8= 2.9977	a_{13}=-1.95535
a_4= 0.033695	a_9= 0.15847	a_{14}=-0.944752
a_5= 0.003165	a_{10}= 0.61596	a_{15}= 0.744787

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+$$
$$+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$





Y[1] между 0 .. 60 %

Y[2] между 60 .. 70 %

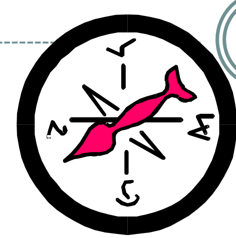
Y[3] между 70 .. 80 %

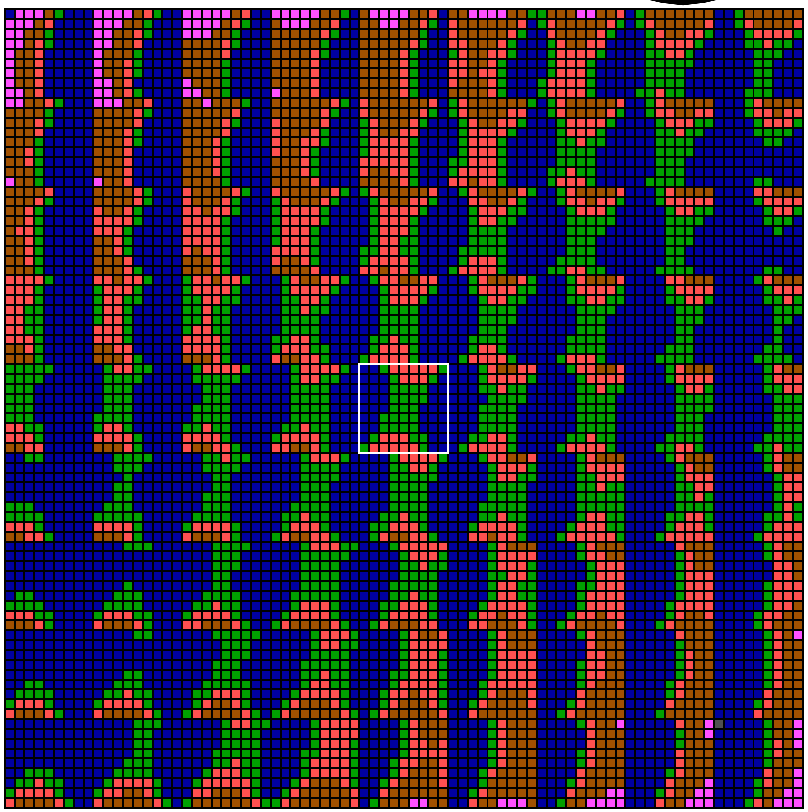
Y[4] между 80 .. 90 %

Y[5] между 90 .. 100 %

a_1= 0.4325	a_6=-1.196	a_{11}= 2.15432
a_2=-0.008248	a_7=-0.259	a_{12}= 1.01693
a_3=-0.228915	a_8= 2.9977	a_{13}=-1.95535
a_4= 0.033695	a_9= 0.15847	a_{14}=-0.944752
a_5= 0.003165	a_{10}= 0.61596	a_{15}= 0.744787

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+$$
$$+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$





Y[1] между 0 .. 70 %

Y[2] между 70 .. 75 %

Y[3] между 75 .. 80 %

Y[4] между 80 .. 90 %

Y[5] между 90 .. 100 %

a_1= 0.4325 a_6=-1.196 a_{11}= 2.15432

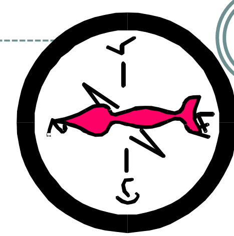
a_2=-0.008248 a_7=-0.259 a_{12}= 1.01693

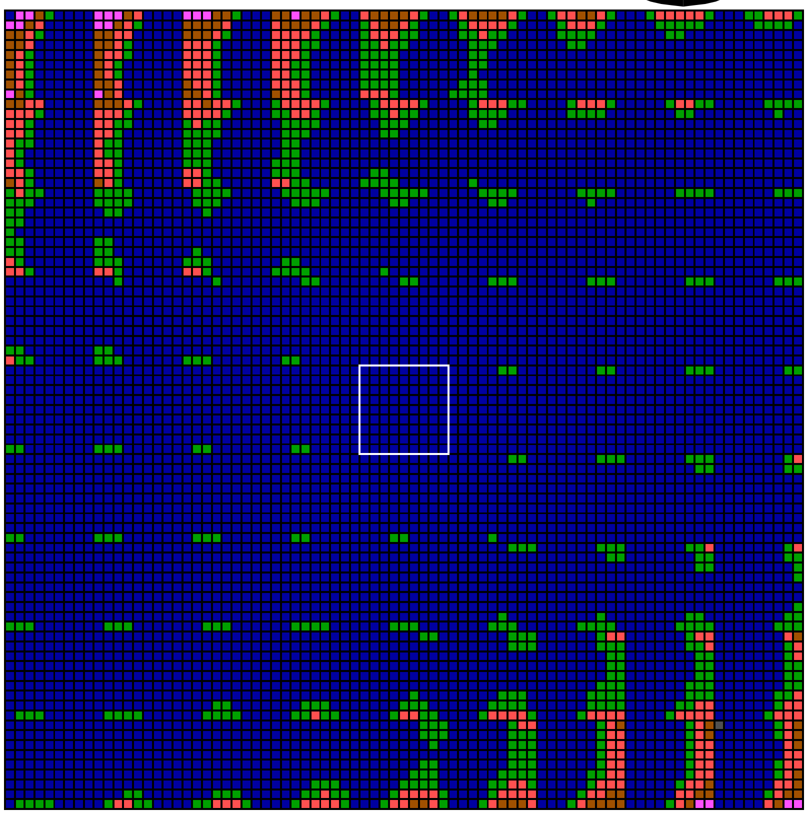
a_3=-0.228915 a_8= 2.9977 a_{13}=-1.95535

a_4= 0.033695 a_9= 0.15847 a_{14}=-0.944752

a_5= 0.003165 a_{10}= 0.61596 a_{15}= 0.744787

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+$$
$$+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$





Y[1] между 0 .. 80 %

Y[2] между 80 .. 85 %

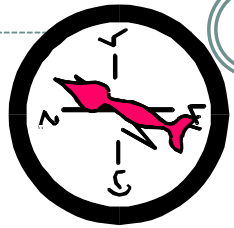
Y[3] между 85 .. 90 %

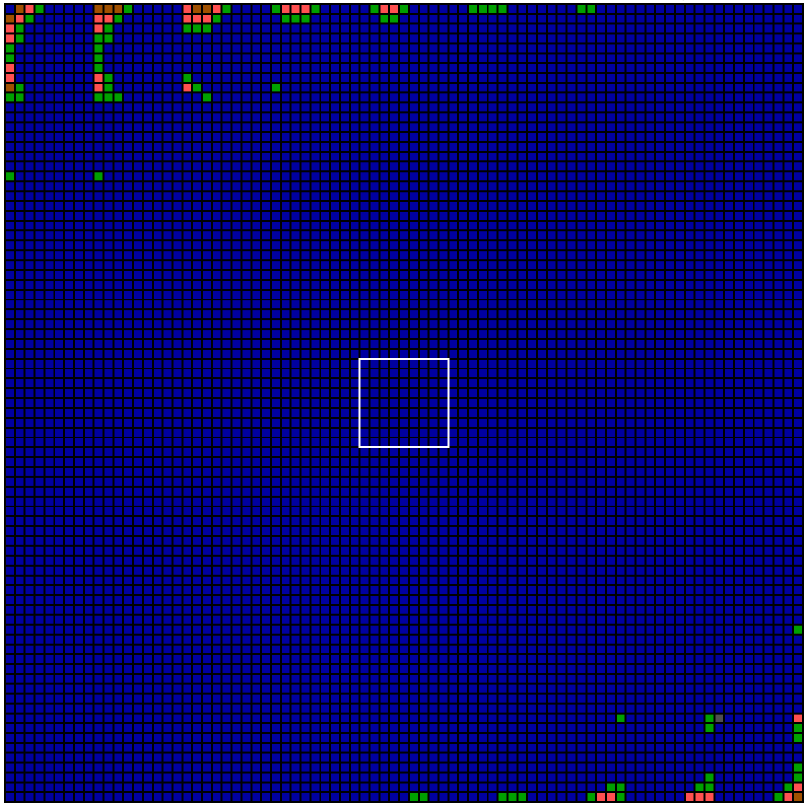
Y[4] между 90 .. 95 %

Y[5] между 95 .. 100 %

a_1= 0.4325	a_6=-1.196	a_{11}= 2.15432
a_2=-0.008248	a_7=-0.259	a_{12}= 1.01693
a_3=-0.228915	a_8= 2.9977	a_{13}=-1.95535
a_4= 0.033695	a_9= 0.15847	a_{14}=-0.944752
a_5= 0.003165	a_{10}= 0.61596	a_{15}= 0.744787

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+ +a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$





Y[1] между 0 .. 90 %

Y[2] между 90 .. 93 %

Y[3] между 93 .. 96 %

Y[4] между 96 .. 99 %

Y[5] между 99 .. 100 %

a_1= 0.4325 a_6=-1.196 a_{11}= 2.15432

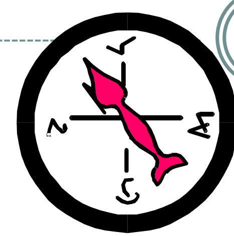
a_2=-0.008248 a_7=-0.259 a_{12}= 1.01693

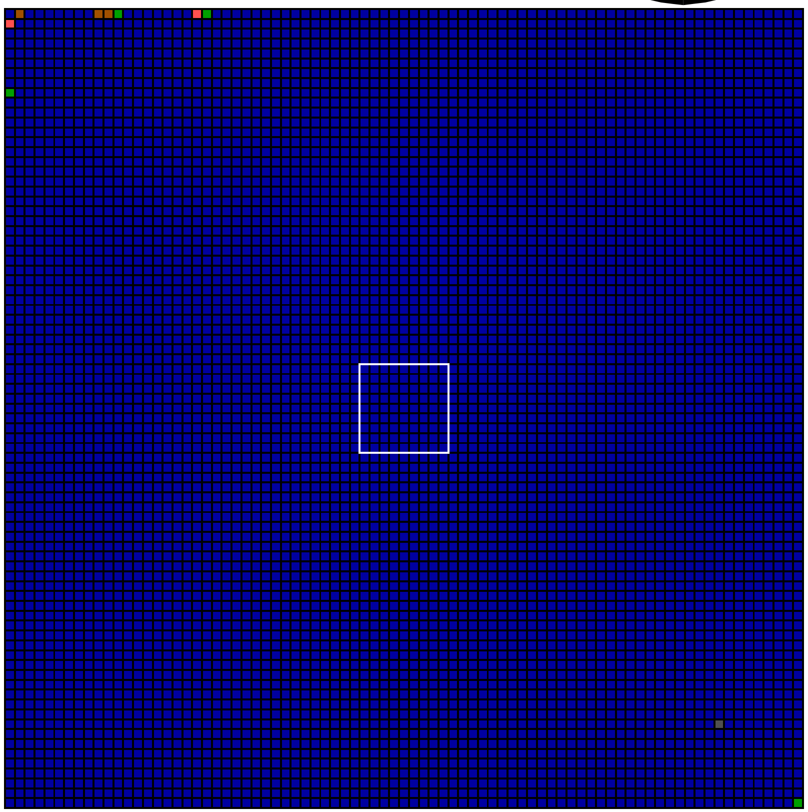
a_3=-0.228915 a_8= 2.9977 a_{13}=-1.95535

a_4= 0.033695 a_9= 0.15847 a_{14}=-0.944752

a_5= 0.003165 a_{10}= 0.61596 a_{15}= 0.744787

$$Y(x_1, x_2, x_3, x_4)=a_1+a_2.x_1+a_3.x_2+a_4.x_3+a_5.x_4+a_6.x_1^2+a_7.x_1.x_2+a_8.x_1.x_3+a_9.x_1.x_4+$$
$$+a_{10}.x_2^2+a_{11}.x_2.x_3+a_{12}.x_2.x_4+a_{13}.x_3^2+a_{14}.x_3.x_4+a_{15}.x_4^2$$





Y[1] между 0 .. 96 %

Y[2] между 96 .. 97 %

Y[3] между 97 .. 98 %

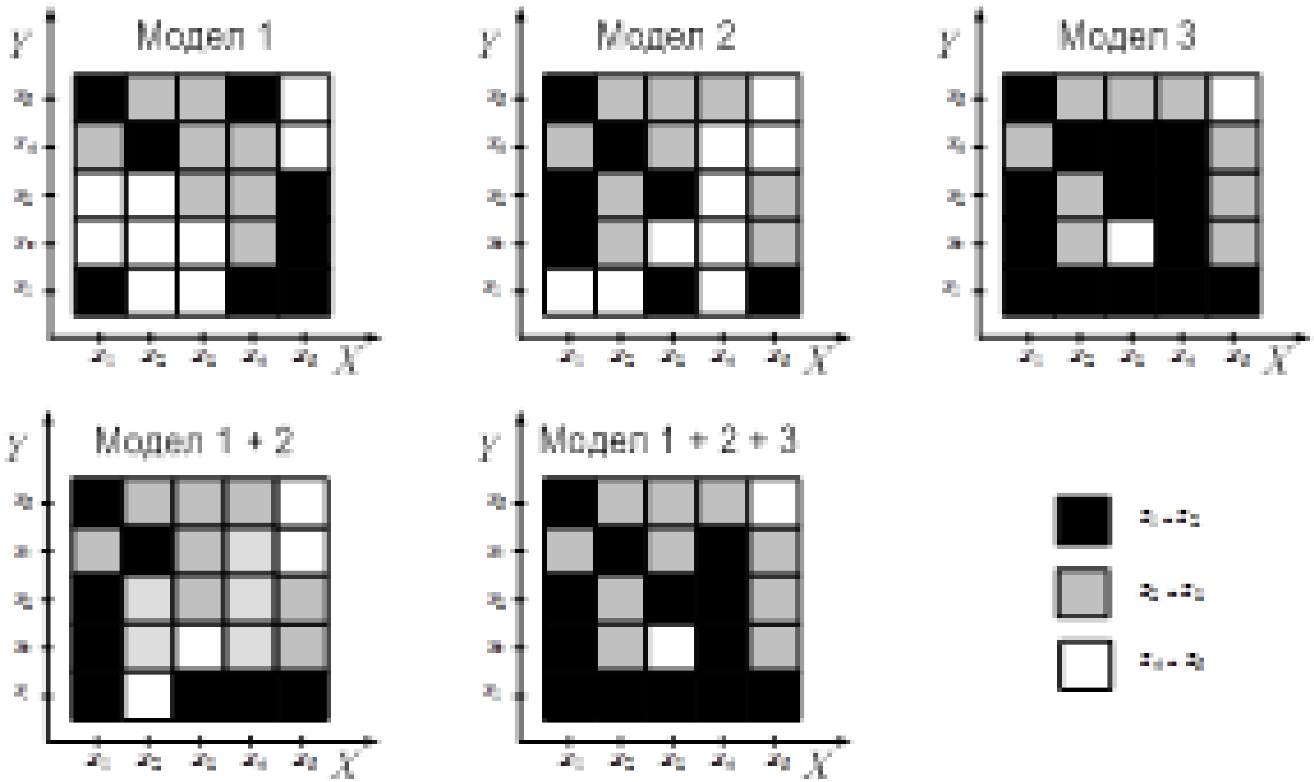
Y[4] между 98 .. 99 %

Y[5] между 99 .. 100 %

a_1= 0.4325	a_6=-1.196	a_{11}= 2.15432
a_2=-0.008248	a_7=-0.259	a_{12}= 1.01693
a_3=-0.228915	a_8= 2.9977	a_{13}=-1.95535
a_4= 0.033695	a_9= 0.15847	a_{14}=-0.944752
a_5= 0.003165	a_{10}= 0.61596	a_{15}= 0.744787

- All this is when we analyze a studied magnitude.
- However, a complex of properties is studied in **M**aterial **S**cience.
- Each property is a criterion.
- We use the same analysis when defining the multi-criterion **problem**.
- But what principle is it based on?
- The example is shown on the next slide.

Graphical interpretation multi-ciriteria optimization



The initial iteration corresponds to a standard color distribution. Usually high **percentages** are unattainable.

The last color in the image is observed, and then its interval is subdivided.

Usually no more than three iterations are required.
In the figures, two of the parameters are changed globally, and the other two locally.

The **value** under investigation is arranged in a certain color in the parameter space.

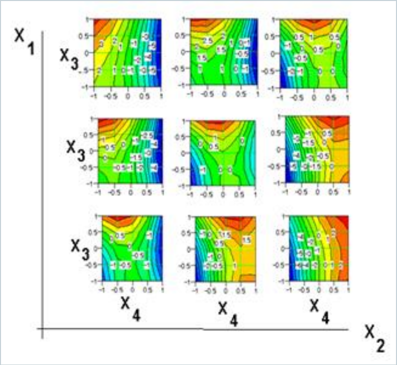
The procedure determines the percentage over which the two properties are when the **solved problem is 'maximum minimum'.**

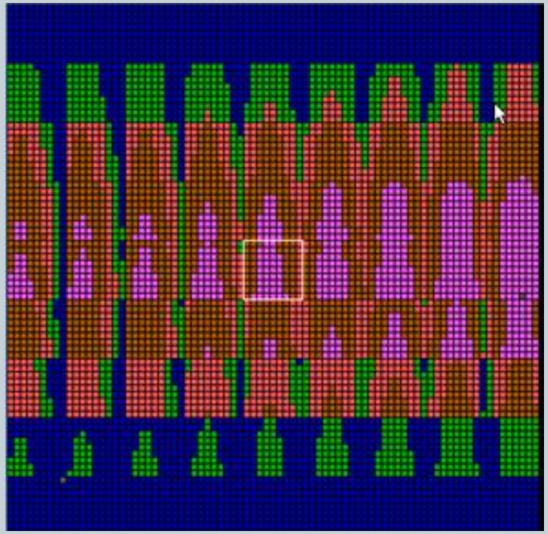
- For a minimum-minimum **problem**, the minim**al** criterion(s) is**(are)** subtracted from 100, and then the new values resolve the 'maximum – maximum' **problem**.
- Therefore, the most important step in the optimization procedure is to bring all the measured quantities to the same scale.
- This is a uniformly distributed scale in the range of 0-100%.
- The minim**al** value of the **research value** corresponds to 0% and the maxim**al** to 100%

Now let's get back to the casting problem.

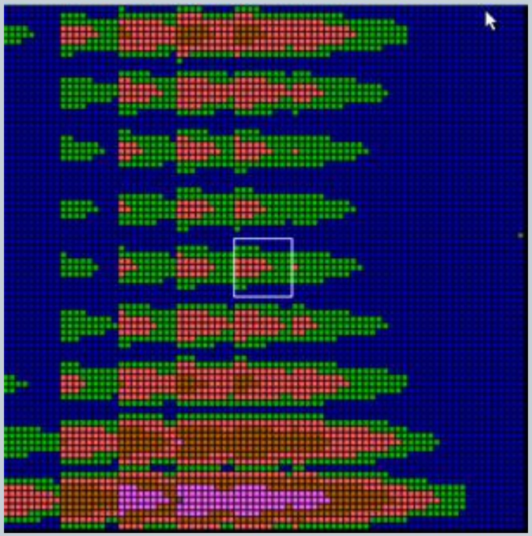
After analyzing the distribution of the DAS characteristics, a **generalized** matrix is formed of the numbers **from** all six matrices.

Distribution of DAS values along the sections during varying technological parameters

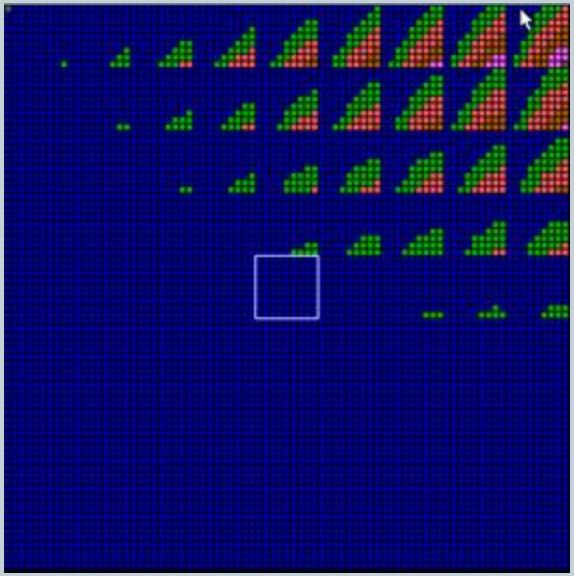




Das1

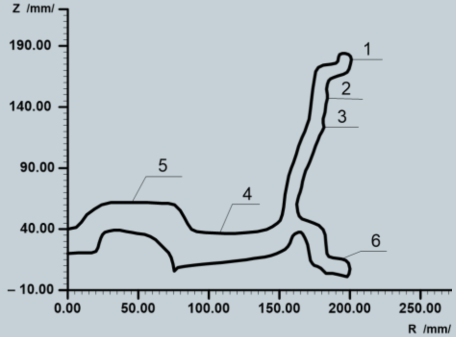


Das5



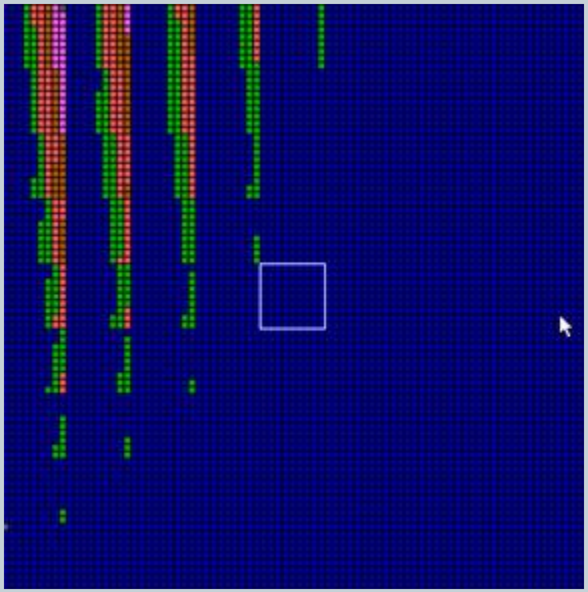
Das2

0.00 – 60.00	
60.00 – 70.00	
70.00 – 80.00	
80.00 – 90.00	
90.00 – 100.0	

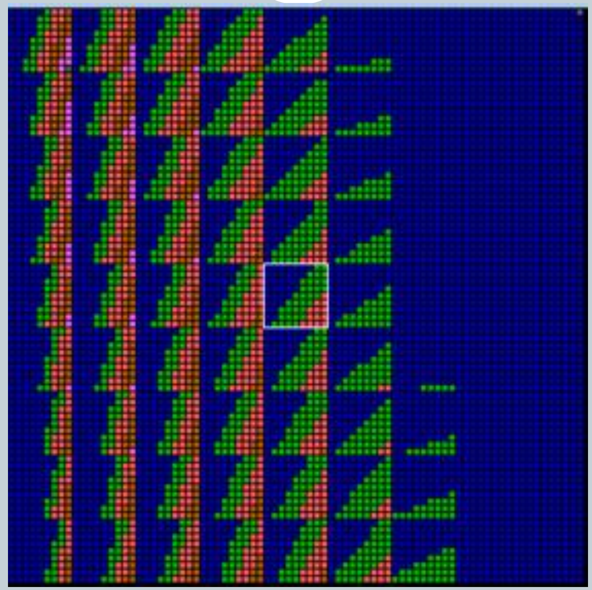


Here Das values are arranged with different colors depending on the four technological parameters. Each panel visualizes Das values of 6,561 combinations of the technological factors.

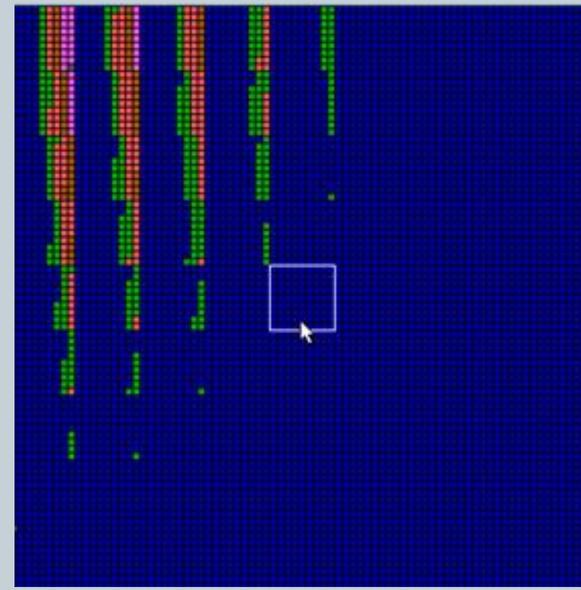
Distribution of DAS values along the sections during varying technological parameters



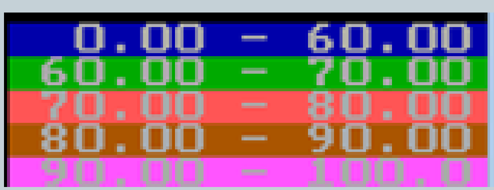
DAS 3

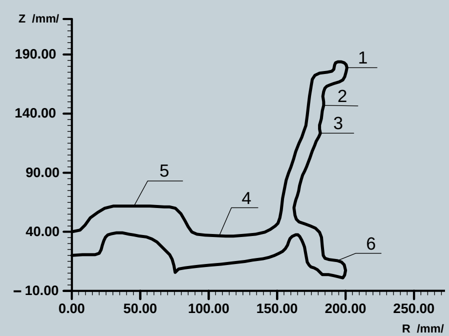


DAS 4



DAS 6

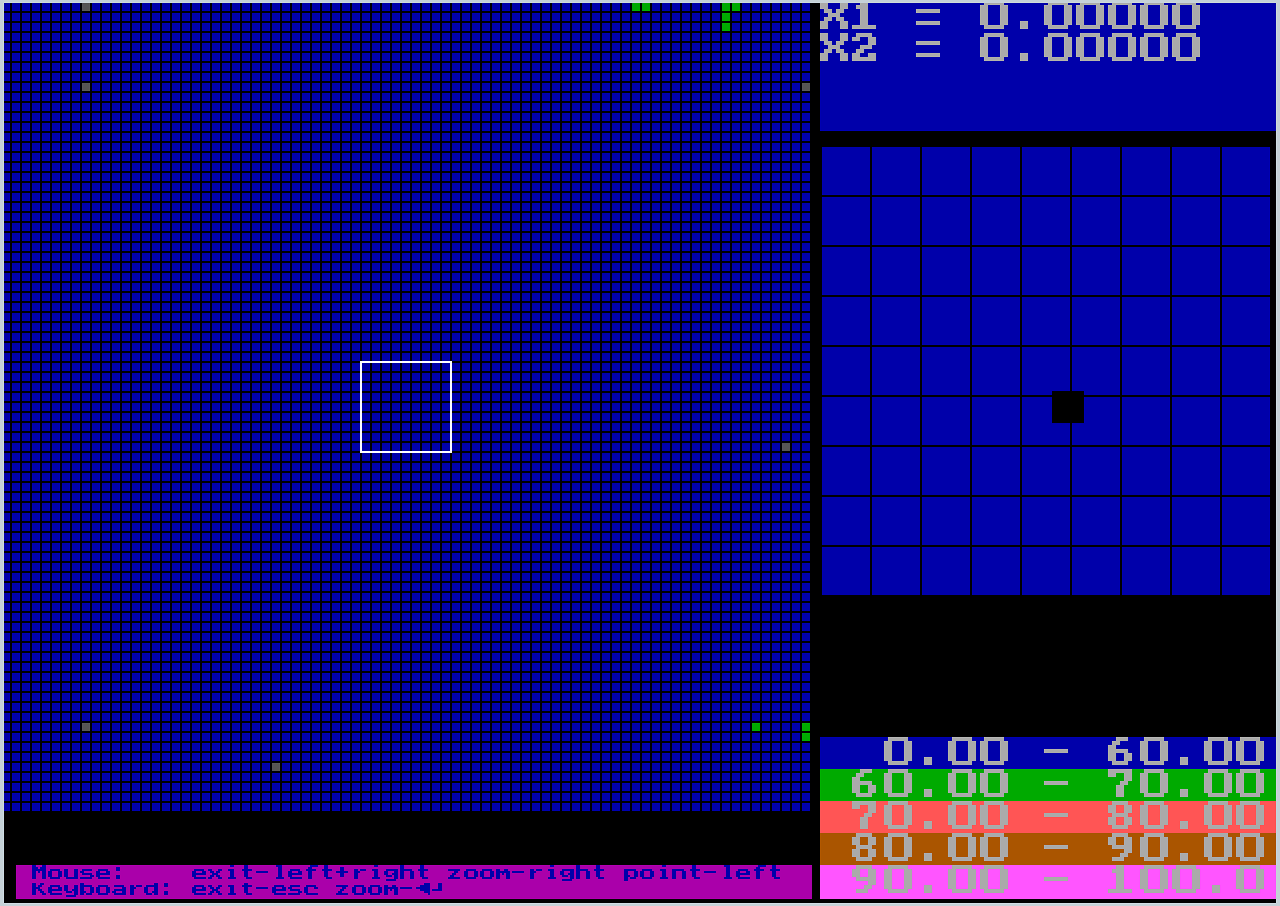




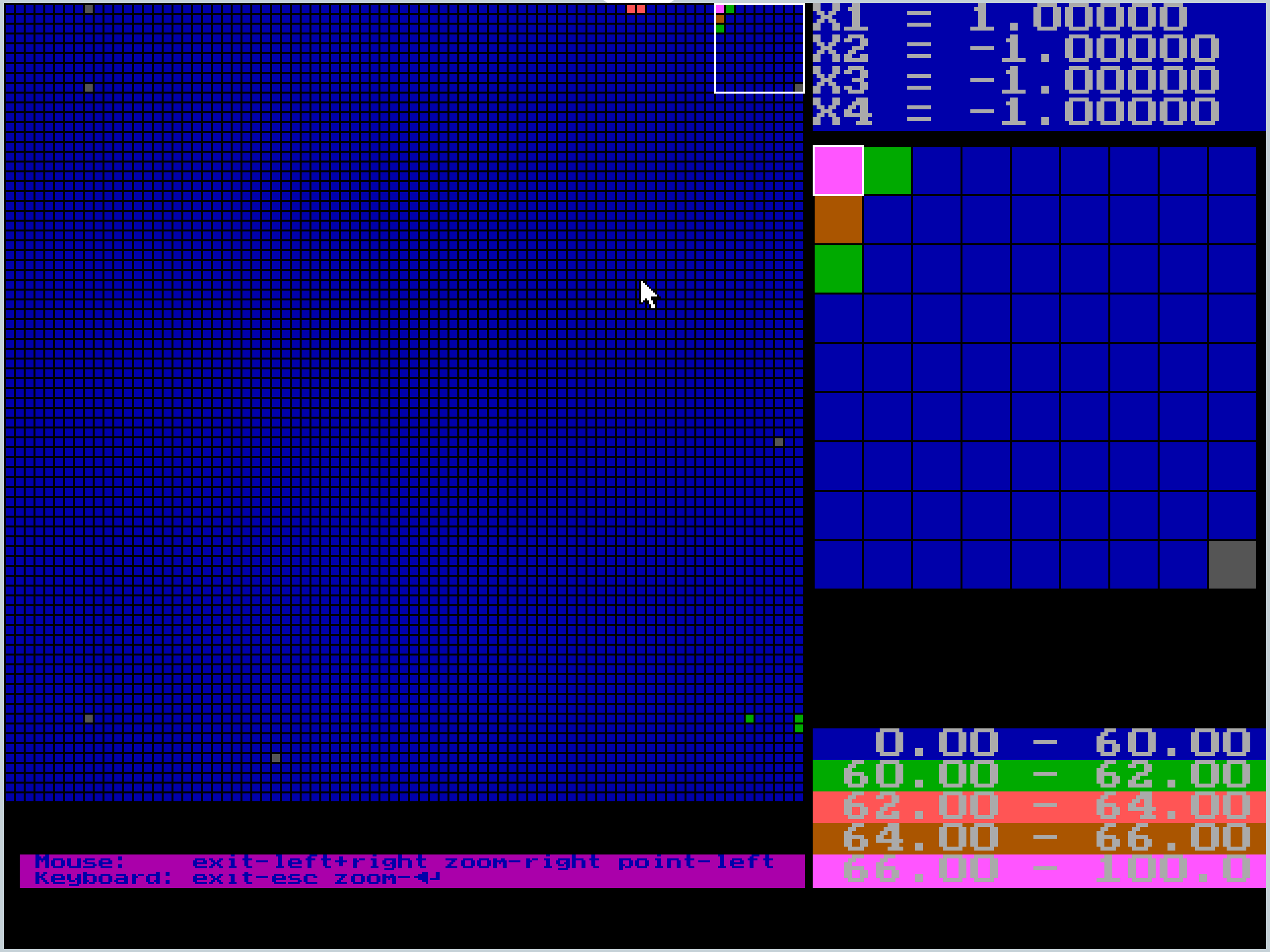
Having Das values in the six sections, the system determines which initial conditions lead to the minimal DAS simultaneously in the six sections.

- All six images are merged and a common area in which **the** minimization is made.
- Here is the illustration in two iterations and these are the regimes.

First iteration



Second iteratcion



Optimal technological modes of casting and values of DAS along the sections for the optimal solutions

	Temperature of the liquid metal	Time of casting	Time between two casting cycles	Counterpressure
1st solution	760	8	60	1.5
2nd solution	760	30	180	1.5

Section	1st solution	2nd solution
DAS1	15	15.8
DAS2	19.9	18.9
DAS3	20.1	18.5
DAS4	25.2	27.9
DAS5	36	37.5
DAS6	17.1	11.3

From the analysis of the two determined solutions it follows that as a complex the second solution is the better one. It is recommended for the final experimentation.

Example # 2 – Ion-nitriding treatment in low-temperature plasma of tool steel

http://www.efttom.com/product/

General type designation	Power kVA	Type of discharge	Number of working chambers	Working chamber design
ION-installation for ion nitriding and carbonitriding	20 50 100 200	D-direct-current I-impulse	a digit (1, 2, 3 ...)	L-with a low cover H-with a high cover S-shaft

Quality parameters examined

Y_1 - Micro-hardness
Y_2 - Fracture toughness
Y_3 - Relative specific wear resistance

- **Process-controlling parameters**
- X_1 - Temperature ion- nitriding treatment
- X_2 - Ammonia pressure
- X_3 - Process duration
- X_4 - Temperature of tempering

Factors	T_{nit}	P	τ	T_{tem}
	[°C]	[Pa]	[h]	[°C]
Levels X	X_1	X_2	X_3	X_4
Zero level (0)	530	300	7	650
Interval of variation	20	150	3	50
Upper level (+I)	550	450	10	700
Lower level (-I)	510	150	4	600

• Laboratory tests of BH11, BH21, BH10 steel types (according BS 4659).
•The examination is carried out by a planed experiment - orthogonal composition plan.

The study presents a possibility to choose appropriate steel of a given class and a corresponding mode of ion-nitriding treeant which can guarantee the achievement of a preliminarily given complex of properties examined. The procedure of mode choice-making takes into con-sideration its energy consu-mption as well. With a number of models available for providing the quality desired it is recommended to choose the one using the least power.

Chemical composition of steel from the class of scope, [%] (GOST, Tool steel, 2010)

Steel	C	Si	Mn	Cr	Mo	W	V
4H5MFS	0.32 - 0.4	0.9 - 1.2	0.2 - 0.5	4.5 - 5.5	1.2 - 1.5	–	0.3 - 0.5
3H3M3F	0.27 - 0.34	0.1 - 0.4	0.2 - 0.5	2.8 - 3.5	2.5 - 3.0	–	0.4 - 0.6
3H2V8F	0.3 - 0.4	0.15 - 0.4	0.15 - 0.4	2.2 - 2.7	Up to 0.5	7.5- 8.5	0.2 - 0.5

Characteristics of the steels in scope (GOST, 2007-2013)

Steel	Yield strength Rm, [MPa]	Tensile strength Re,[MPa]	Elongation, A[%]	Reduction of area Z , [%]	Impact strength KCU, [kJ/m^2]
4H5MFS	1750	1480	–	–	570
3H3M3F	1670	1470	–	50	220
3H2V8F	1530	1390	12	36	200

X_1	X_2	X_3	X_4	4Х5МФС HV$_{0,1}$ MPa	3Х3М3 Ф HV$_{0,1}$ MPa	3Х2В8 Ф HV$_{0,1}$ MPa	No	X_1	X_2	X_3	X_4	4Х5МФС HV$_{0,1}$ MPa	3Х3М3 Ф HV$_{0,1}$ MPa	3Х2В8Ф HV$_{0,1}$ MPa
-1	-1	-1	-1	10970	11140	11310	16	+1	+1	+1	+1	10500	10480	10480
+1	-1	-1	-1	10800	10800	11310	17	+1.4	0	0	0	12060	11680	11310
-1	+1	-1	-1	10200	10970	12060	18	-1,4	0	0	0	11680	11000	11140
+1	+1	-1	-1	12060	11860	11080	19	0	+1,4	0	0	10970	10640	10970
-1	-1	+1	-1	11490	11490	12660	20	0	-1,4	0	0	10480	12060	10640
+1	-1	+1	-1	12250	11300	11680	21	0	0	+1,4	0	11490	11310	10170
-1	+1	+1	-1	10170	12060	11680	22	0	0	-1,41	0	11680	10640	11680
+1	+1	+1	-1	11490	11300	10970	23	0	0	0	+1,4	12060	11140	11000
-1	-1	-1	+1	9980	10970	10480	24	0	0	0	-1,4	11310	10970	10640
+1	-1	-1	+1	10480	10480	10170	25	0	0	0	0	11680	11860	11410
-1	+1	-1'	+1	10170	11000	10640	26	0	0	0	0	11000	11680	11140
+1	+1	-1	+1	11310	10640	11000	27	0	0	0	0	11490	11860	11310
-1	-1	+1	+1	11240	11000	10000	28	0	0	0	0	12060	11680	11310
+1	-1	+1	+1	10970	10480	10970	29	0	0	0	0	11490	11680	11410
-1	+1	+1	+1	10170	10320	9320	30	0	0	0	0	11680	11860	11410

For this example, below is given the relation between the technological factors and the goal examples. Their methodologies are given in Zyumbilev A. (1992).

For steel **4H5MFS**

$HV_{0.1}$= 11914.4+254.13X_1-143.65X_2+134.44X_3-274,03X_4-51.50X_1^2+248.75X_1X_2-88.75X_1X_3-136.25X_1X_4-624.00X_2^2-301.25X_2X_3+76.25X_2X_4+194.00X_3^2-36.25X_3X_4-144.00X_4^2

K_Q= Y_4= 83.2-1.52X_1+5.3X_2+3.77X_3+1.89X_4-3.75X_{12}+4.63X_1X_2-4.00X_2^2-3.5X_4^2

K_V= 0.$_{4020}$-0.0828X_1+0.0033X_2-0.0523X_3-0.0008X_4+0.0037X_1^2+0.0106X_1X_2+0.0244X_1X_3-0.0006X_1X_4+0.0087X_2^2-0.0469X_2X_3+0.0031X_2X_4+0.0237X_3+0.0093X_3X_4+0.0512X_4^2

For steel **3H3M3F**

$HV_{0.1}$= 11527.2-129.5X_1+150.41X_2-292.02X_4+87.50X_1X_2-62.50X_1X_3-75X_2X_3-137.50X_2X_4-234.5X_3^2-137.50X_3X_4-194.50X_4^2

K_Q= Y_8= 74.76-2.24X_1-1.76X_2-0.52X_3+19.06X_4-16.1X_1^2+2.13X_1X_2-2.5X_1X_3-X_1X_4-17.35X_2^2+1.25X_2X_3-2.25X_2X_4+14.65X_3^{2+}0.88X_3X_4-8.85X_4^2

K_V= 0.3898-0.0786X_1-0.0099X_2-0.0494X_3+0.0151X_4+0.0307X_1^2+0.0131X_1X_2+0.0044X_1X_3+0.0157X_1X_4+0.0257X_2^2-0.0494X_2X_3+0.0243X_2X_4+0.0107X_3^2-0.0218X_3X_4+0.0457X_4^2

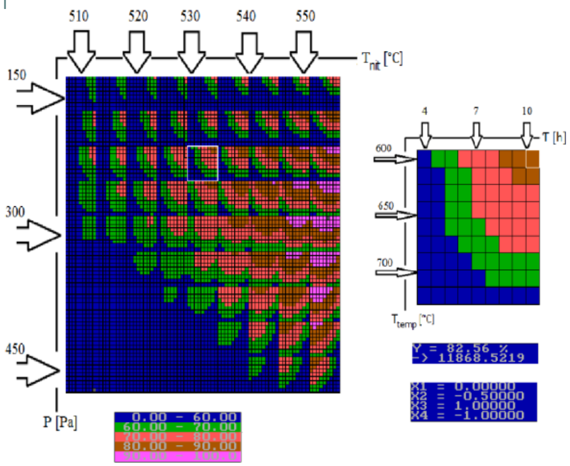
For steel **3H2V8F**

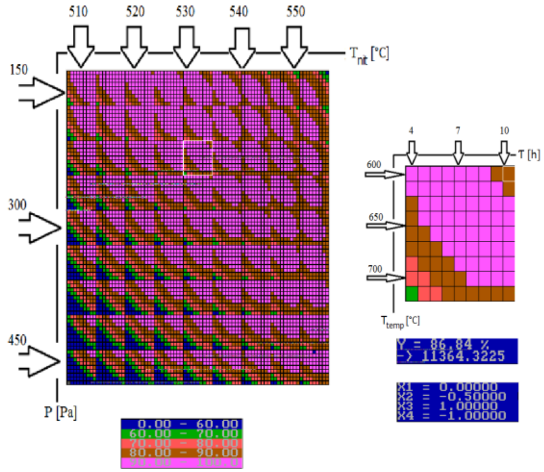
$HV_{0.1}$ = 11074.8-92.33X_2+97.99X_3-514.46X_4+117.00X_1^2+86.25X_1X_3+311.25X_1X_4-93.00X_2^2-273.75X_2X_3-173.75X_3X_4-85.50X_4

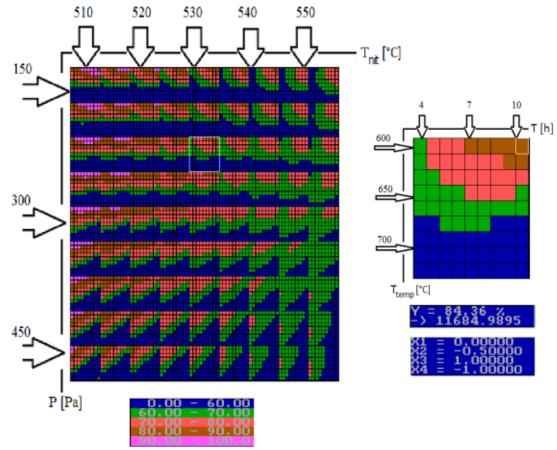
K_Q= Y_{12}= 40.52-9.3X_1-1.8X_2-3.49X_3+13.49X_4-2.7X_1^2+0.625X_1X_2-5.25X_1X_4-2.20X_2^2+0.125X_2X_3-2.95X_3-3.38X_3X_4+13.05X_4^2

K_V= Y_{14}= 0.3804-0.0804X_1-0.0076X_2-0.0504X_3+0.0300X_4+0.0156X_1^2+0.0050X_1X_2-0.0025X_1X_3+0.0037X_1X_4+0.385X_2^2-0.054X_2X_4-0.029X_3^2-0.037X_3X_4+0.059X_4^2 (2-9)

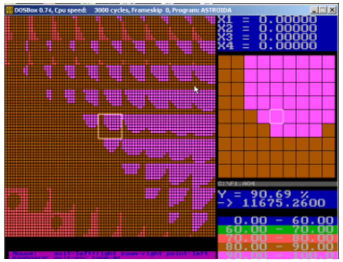
parameters	$H_{\mu V}$ ($HV_{0.1}$) for steel		
	4H5MFS	3H3M3F	3H2V8F
Free	11675.26	11813.49	11232.81
x_1	300.3842	462.604	-12.78176
x_2	-70.86131	-546.9271	-44.17166
x_3	102.0732	570.9035	-121.2643
x_4	-177.4857	-760.527	-459.0758
$x_1 . x_2$	239.375	710.625	9.375
$x_1 . x_3$	-74.375	-681.875	85.625
$x_1 . x_4$	-129.375	568.125	303.125
$x_2 . x_3$	-320.625	544.375	-273.125
$x_2 . x_4$	66.875	-740.625	61.875
$x_3 . x_4$	-26.875	481.875	-171.875
x_1^2	15.95109	-269.4298	70.23389
x_2^2	-556.7208	-264.4267	-139.8285
x_3^2	-126.592	-451.9834	-79.80983
x_4^2	-76.57547	-411.9729	-132.3259
R^2 =	0.85549	0.819219	0.8211649
Fcalc > Ftabl	2.92458 > 2.4244	2.18637 > 2.4244	2.2183 > 2.4244

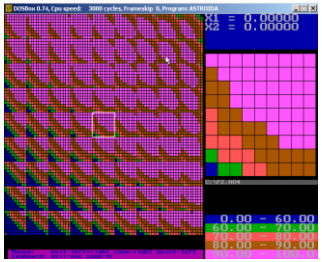


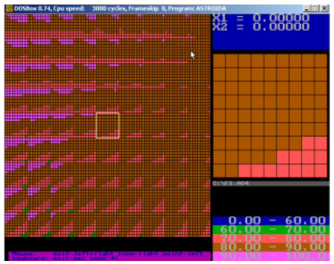




Distribution of microhardness in the test domain of input parameters - 4H5MFS, 3H3M3F, 3H2V8F.

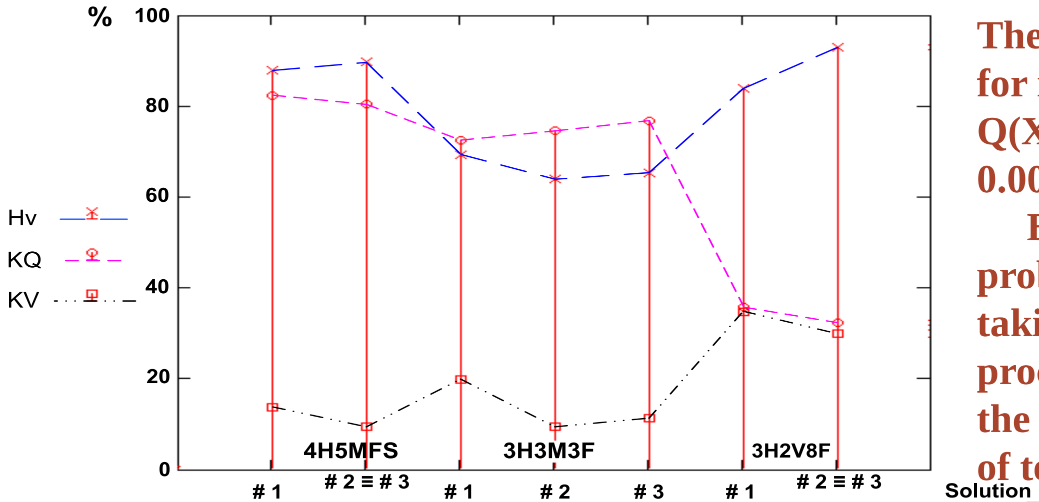






Distribution of microhardness against common basis, in the test domain of input parameters
- 4H5MFS, 3H3M3F,
3H2V8F

Graphic interpretation of a comparative research of the multicriteria problem in the class of heat-resistant steels



Parameters	4H5MFS		3H3M3F			3H2V8F	
	#1	#2 ≡ #3	#1	#2	#3	#1	#2 ≡ #3
X_1	0.5	1	- 0.25	0.25	0	- 1	- 1
X_2	0.25	0.25	0.0	0.5	0.5	- 0.25	- 0.25
X_3	0.75	0.75	0.25	1	1	0	1
X_4	- 0.5	- 0.25	0	- 0.25	- 0.25	- 1	- 1
Hv	12060	12110	11550	11410	11440	11950	12200
K_Q	84.16	82.29	75.25	77.18	79.04	41.89	38.80
K_V	0.348	0.312	0.399	0.313	0.329	0.523	0.483

The relative power consumption of the process for ion nitriding is:

$$Q(X_1, X_2) = 1.13 + 0.0837 X_1 + 0.0563 X_2 + 0.008 X_1^2 – 0.0176 X1X_2 – 0.0123X_2^2$$

Based on the proposed approach to the problem of selection of technology solutions, taking into account the information assurance, procedures have been developed to search for the relevant mode, supplementing the archives of technological solutions.

The joint analysis of together with the expended power, determines decision # 1 of steel 4H5MFS as the most effective of the class of heat-resistant steels with corresponding treatment. An approach based on the method described above selects a representative of a given class to meet the preset requirements.

MADMML Application Domain

MADMML can be successfully applied to:

- identifying experimental results;

- analysis of multi-parameter regression models;

- determining trade-off solutions.

The MADMML software gives possibilities to code the limits of different parameters change with the study of innovation technology or other processes at the beginning of calculations. The purpose of the software is to help the researcher who is interested to keep the secret of effective solutions.

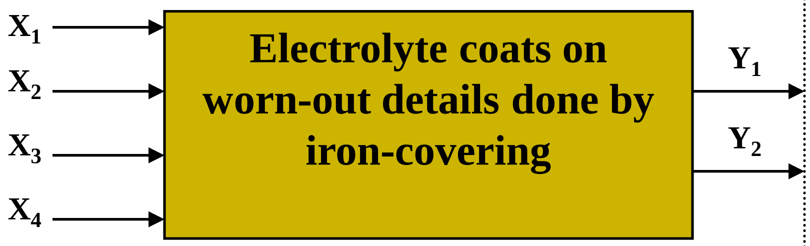
MADMML Previous Investigations

Process-controlling parameters

X_1 - Concentration of manganese and nickel in the electrolyte
X_2 - Cathode and anode indicator
X_3 - Average cathode current density
X_4 - Temperature of the electrolyte

Quality parameters examined

Y_1 - Contain of manganese in coating
Y_2 - Contain of nickel in coating



The combination of process-controlling parameter values simultaneously ensuring the maximum deposition of manganese and nickel in electrolyte alloy are determined.

- **The laboratory tests of 530A40 (according BS 970) steel aiming at applying the results to detail restoration.**
- **The examination is carried out by planed experiment - orthogonal composition plan.**

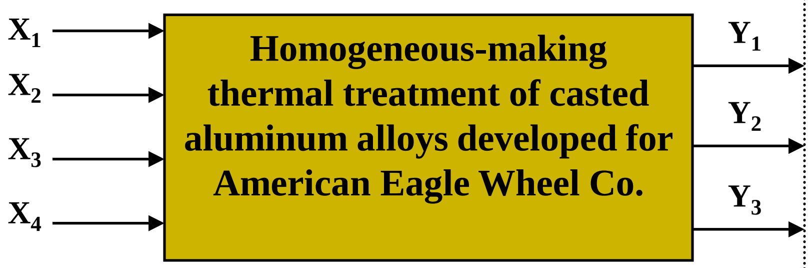
MADMML Previous Investigations

Process-controlling parameters

X_1 - Temperature of homogenization annealing
X_2 - Duration of diffusion annealing
X_3 - Temperature of treatment
X_4 - Duration of treatment

Quality parameters examined

Y_1 - Ultimate tensile strength
Y_2 - Yield-point stress
Y_3 - Relative specific elongation



The technology parameter changing range is determined to satisfy the requirements for preliminarily given values of mechanical indicator of two different in thickness wheel rim sections.

- **A number of passive experiment samples of different in thickness and location aluminum wheel rim sections are examined with a real production process.**

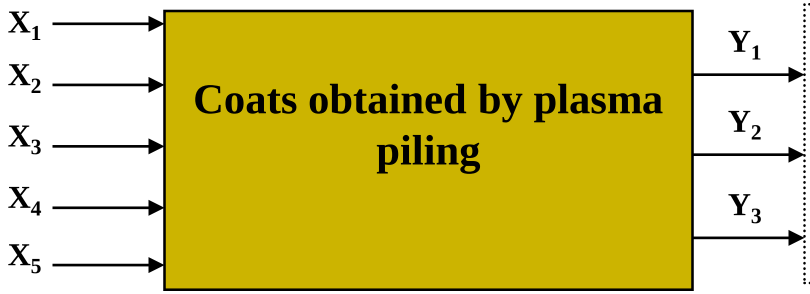
MADMML Previous Investigations

Process-controlling parameters

X_1 - Consumption of plasma-producing gas
X_2 - Electric arc amperage
X_3 - Distance of piling
X_4 - Displacement speed
X_5 - Powder consumption

Quality parameters examined

Y_1 - Adhesion of the plasma coating
Y_2 - Micro-hardness of the plasma coating
Y_3 - Porosity of coating



The complex effect of the five process-controlling parameters is determined aiming at accomplishment optimal quality parameters control .

- **To accomplish the project a planed experiment has been used with Rehshafner's plan.**

MADMML Previous Investigations

Process-controlling parameters

X_1 - Temperature ion- nitriding treatment
X_2 - Ammonia pressure
X_3 - Process duration
X_4 - Temperature of tempering

Quality parameters examined

Y_1 - Micro-hardness
Y_2 - Fracture toughness
Y_3 - Relative specific wear resistance

The study presents a possibility to choose appropriate steel of a given class and a corresponding mode of ion-nitriding treatment which can guarantee the achievement of a preliminarily given complex of properties examined. The procedure of mode choice-making takes into consideration its energy consumption as well.With a number of models available for providing the quality desired it is recommended to choose the one using the least power.

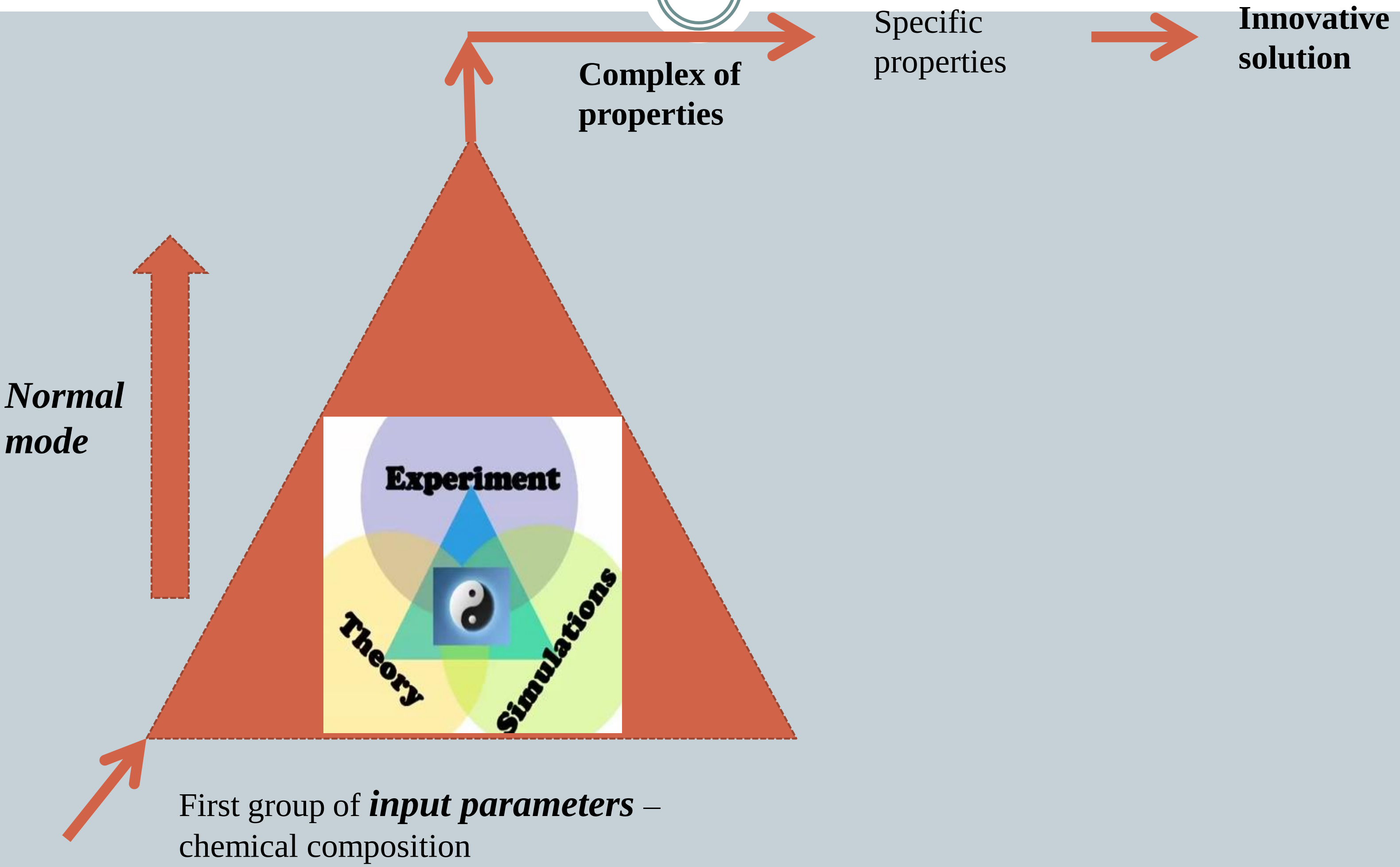
- **Laboratory tests of BH11, BH21, BH10 steel types (according BS 4659).**
- **The examination is carried out by a planed experiment - orthogonal composition plan.**

The second branch that I shall present to You also comes from the subject of material science.

The **division** of parameters is conditional.

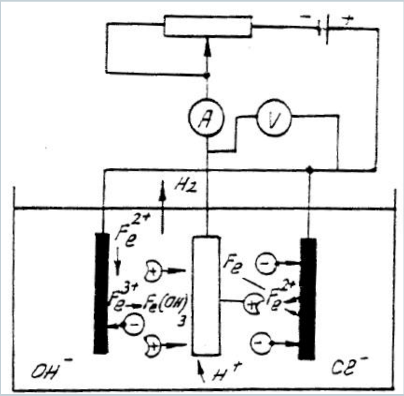
The example is **for** an electrolytic process for the deposition of manganese-cobalt and nickel coatings.

Second application of the normal problem for the field of performance of contract No. 1256/27.04.15.

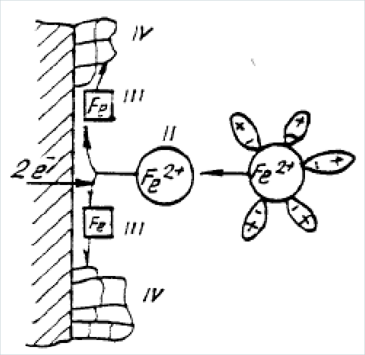


We have accumulated experience and software is produced to fix the impact of separate components on the composition and its final properties. This task is named for short metal design and it is directly related to my second thesis. The goal for it was to elaborate tools that can allow independently of the used data base to improve the properties for which the conditions of the improvement are defined.

Graphs and apparatus of the experiment



Schematic diagram of the electro-chemical and chemical processes



Stages to obtain electrolytic coating

Composition of the electrolytes to obtain multicomponent electrolytic coatings

Electrolyte composition	$FeCl_2 4H_2O$	$NiCl_2 4H_2O$	$CoCl_2 4H_2O$	$MnCl_2\ 6H_2O$	pH
№1	300g/l	10g/l	10g/l	10g/l	0,8
№2	300g/l	25g/l	25g/l	25g/l	0,8

Maintaining a constant ratio between the components in the electrolyte is achieved by periodic chemical analysis and on the basis of the obtained results was added and the corresponding quantity of concentrated solutions of manganese, cobalt and nickel chloride. During the investigation we used a thyristor source of sinusoid asymmetric current and cylindrican specimens of steel 40X with diameter 10 mm and a total area of the coating 0,01m^2. The content of Fe, Ni, Co and Mn in the composition coating is determined by the method of X-ray analysis by a X-ray microprobe type EDS-system of Tracor-USA company equipped with a silicon detector and a beryllium window.

Technological factors of the process

Factors for deposition of iron-nickel-cobalt-manganese coatings	Step of fluctuation	Levels of coded factors				
		-1,414	-1	0	1	1,414
Salt concentration in the electrolyte Z_1 (g/l) C	10	5,86	10	20	30	34,14
Cathode-anode indicator Z_2-ß	6	0,54	3	9	15	17,48
Average cathode current density Z_3,(kA/m2) Дкср (?)	2	0,672	1,5	3,5	5,5	6,328
Electrolyte temperature Z_4 (K) T	20	305	313	333	353	361

- Technological factors are 4, the **explored** parameters are the content of the deposited components in percentages.
- **Microhardness** and tribological tests were performed on these coatings. Here the problem consists of two stages.
- 1. How technological factors influence the electrolytic process and in the second **place**
- 2. How the different coating content affects both properties,: micro-hardness and wear.
- The solution to this **problem** has determined a technological mode that offers maxim**al** hardness of the coating and minimal wear.

Preliminary experiments on the proposed plan to determine the percentage of every element in the coating

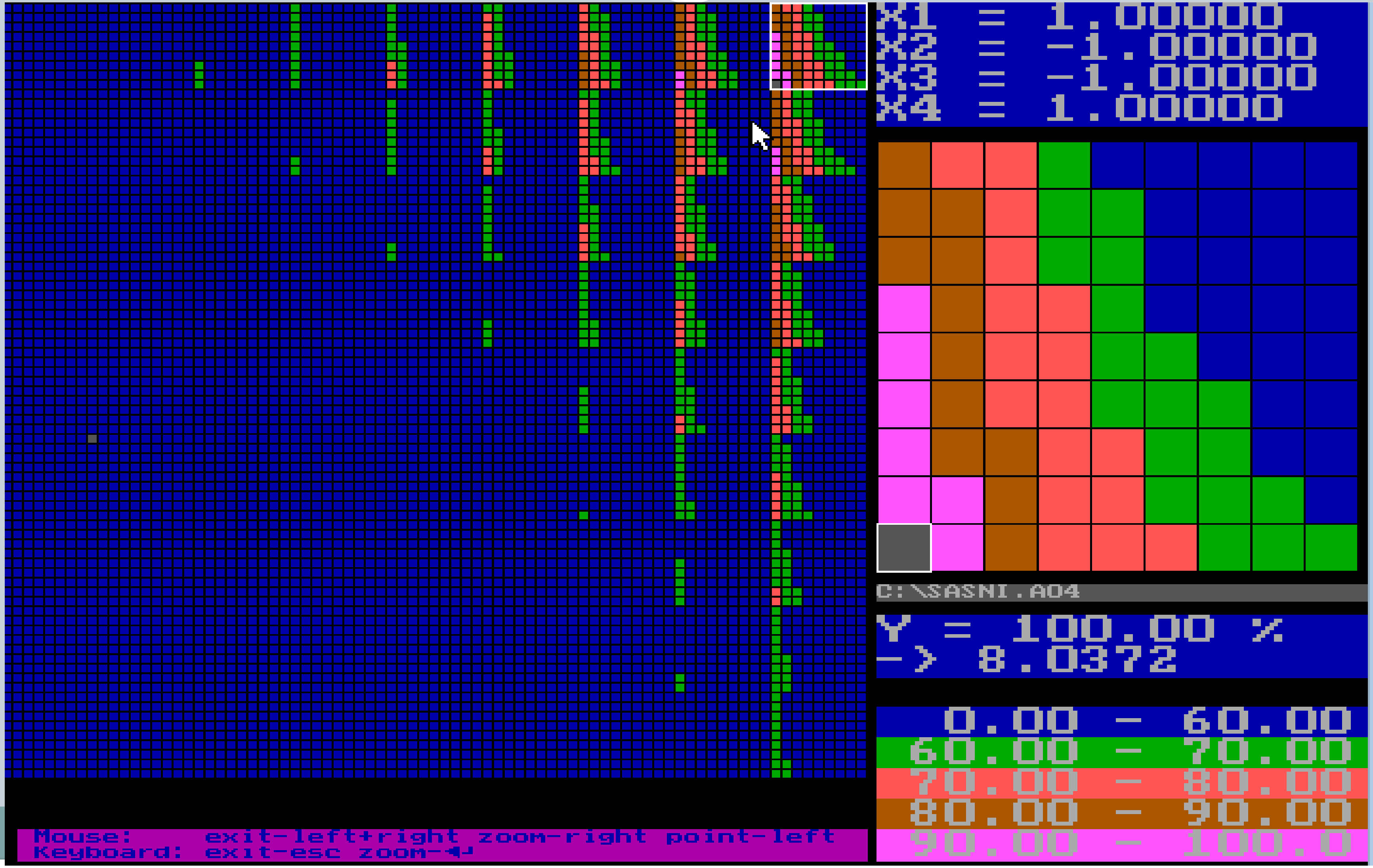
№	C [g/l] - Z_1	ß - Z_2	Дк$_{ср}$ - Z_3	T [K] – Z_4	Mn - X_1	Ni - X_2	Co - X_3
1	30	15	5,5	353	4,79	4,75	4,50
2	10	15	5,5	353	1,35	2,35	2,10
3	30	15	1,5	353	5,05	5,85	5,60
4	10	15	1,5	353	1,18	2,25	2,00
5	30	15	5,5	313	6,15	4,25	3,98
6	10	15	5,5	313	3,00	1,85	1,65
7	30	15	1,5	313	5,05	5,75	5,50
8	10	15	1,5	313	1,20	3,50	3,25
9	30	3	5,5	353	3,65	5,25	5,01
10	10	3	5,5	353	3,21	2,05	1,80
11	30	3	1,5	353	5,00	7,90	7,55
12	10	3	1,5	353	1,15	4,90	4,65
13	30	3	5,5	313	5,80	5,10	4,85
14	10	3	5,5	313	2,95	1,95	1,70
15	30	3	1,5	313	4,15	6,50	6,20
16	10	3	1,5	313	2,78	4,85	4,60
17	34,14	9	3,5	333	4,35	5,65	5,40
18	5,86	9	3,5	333	0,95	1,80	1,55
19	20	17,48	3,5	333	4,51	2,30	2,05
20	20	0,54	3,5	333	2,69	5,15	4,90
21	20	9	6,328	333	6,02	1,75	1,51
22	20	9	0,672	333	2,91	6,25	6,00
23	20	9	3,5	361	3,68	4,15	3,85
24	20	9	3,5	305	3,51	2,35	2,12
25	20	9	3,5	333	3,61	3,85	3,60

Presenting the multicriteria approach

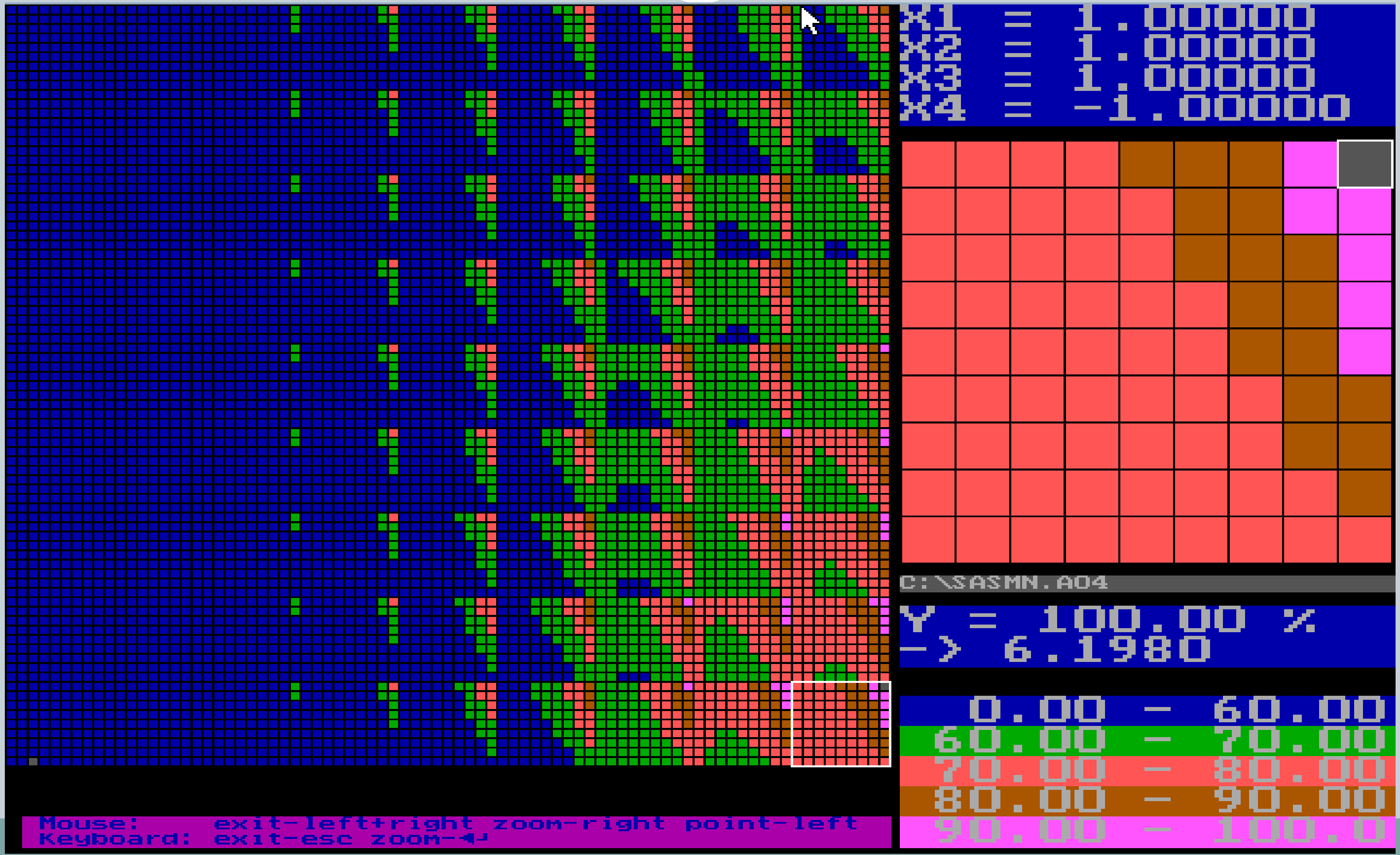
An approach is formulated for numeric solution of single- and multicriteria problems for optimization of the choice of metallic materials and the technological version of their processing.

Methodology is developed ensuring the necessary complex of properties with controlling material and power expenses. Specialized software is elaborated for the automated application of this approach.

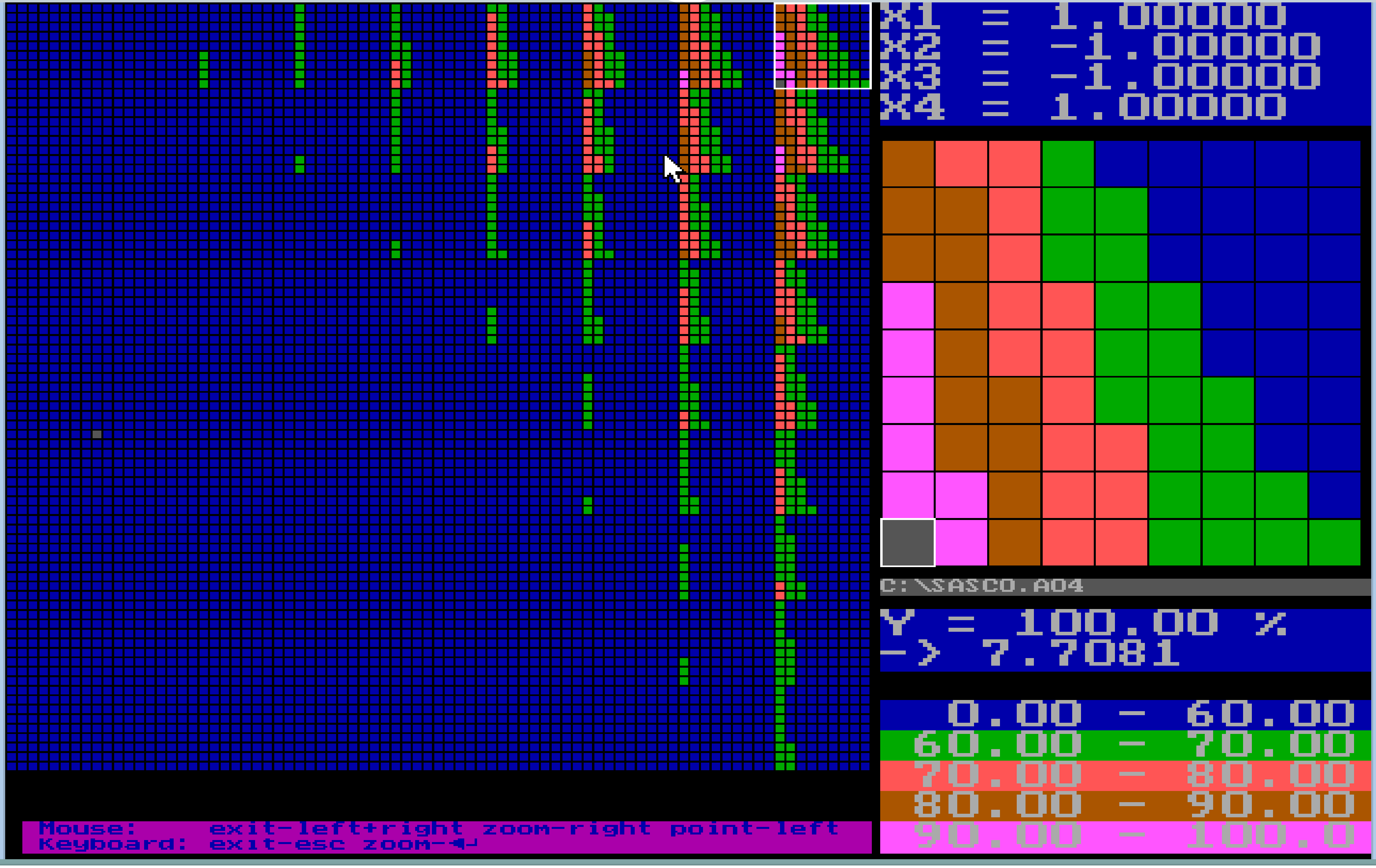
Distribution of nickel percentage in the electrolytic coating relative to varying the four technological factors



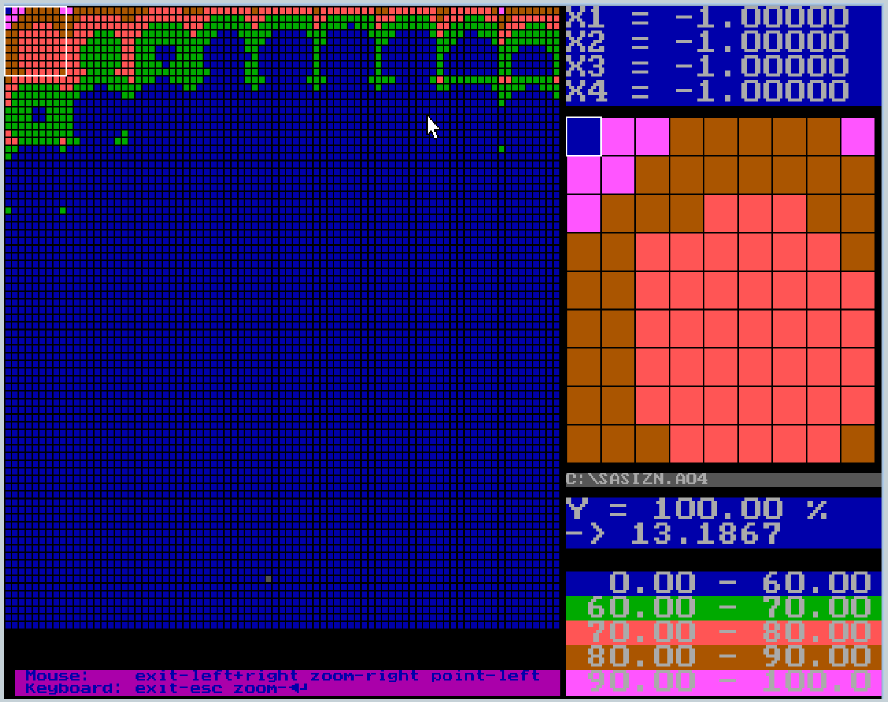
Distribution of manganese percentage in the electrolytic coating relative to varying the four technological factors

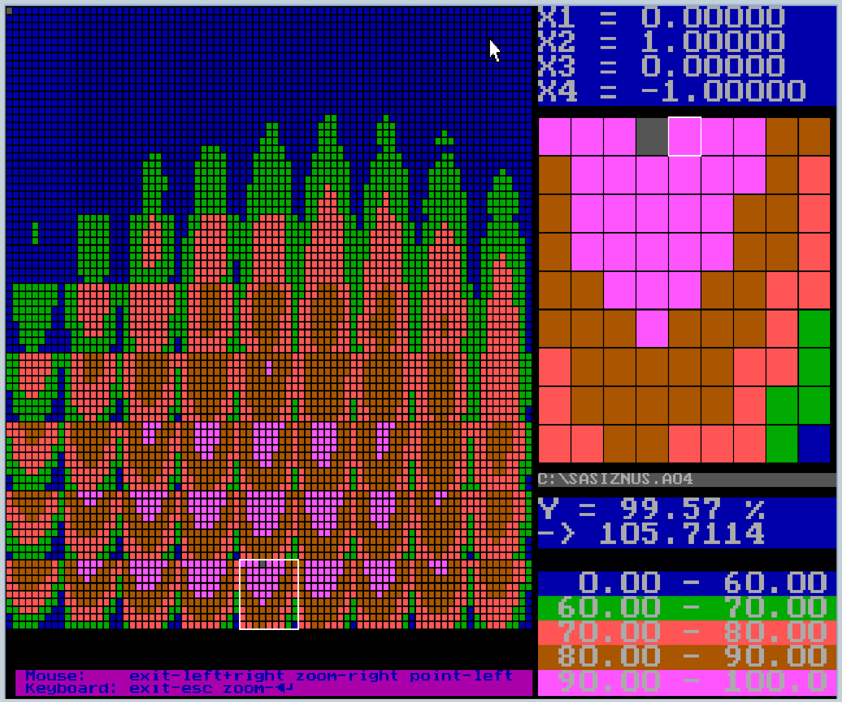


Distribution of cobalt percentage in the electrolytic coating relative to varying the four technological factors



Distribution of a) wear and b) the wear resistance relative to the variation of the four technological factors

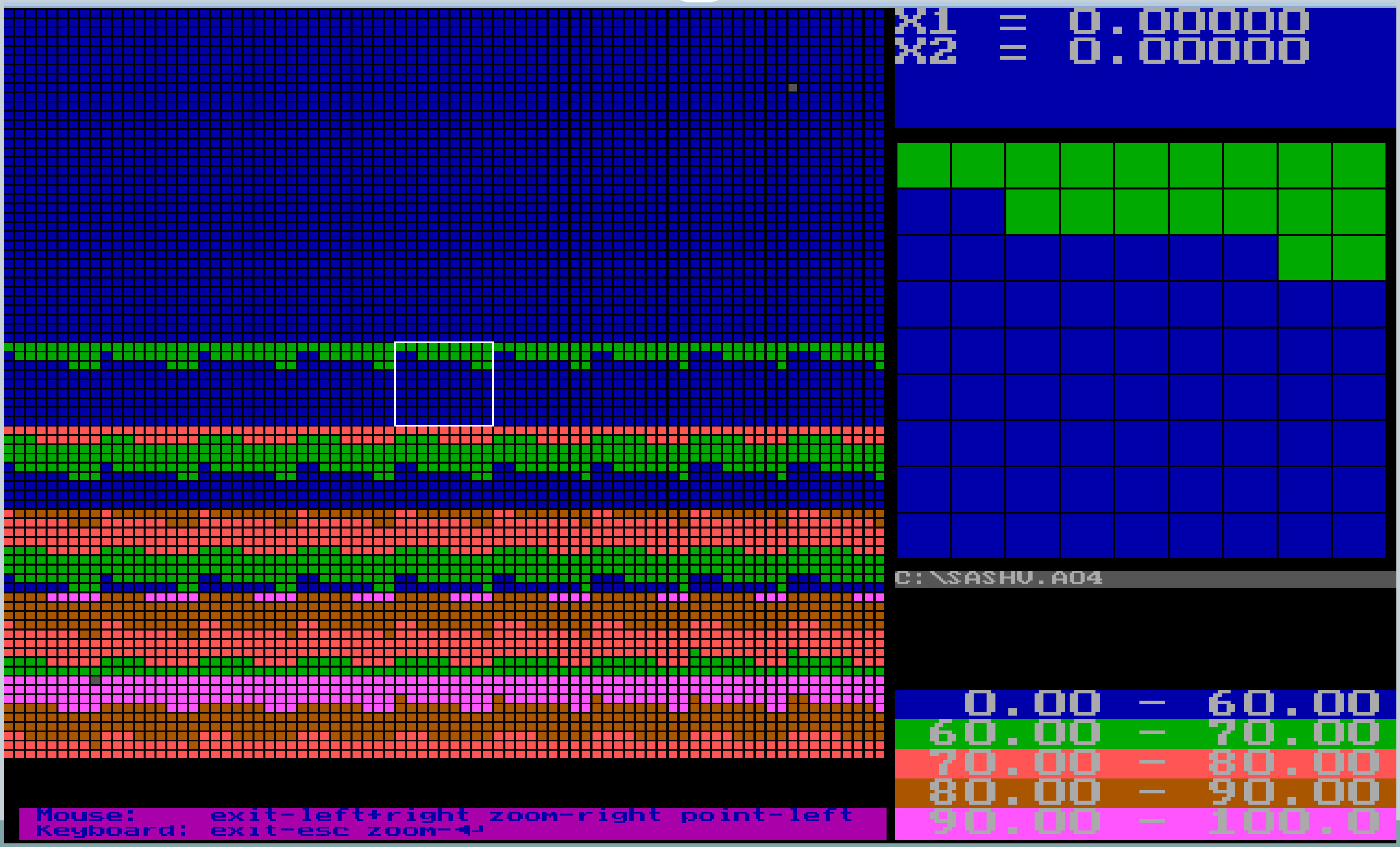




a) b)

The reciprocity of the parameters is very obvious.

Distribution of hardness relative to varying the four technological factors



Models used to compile the data base

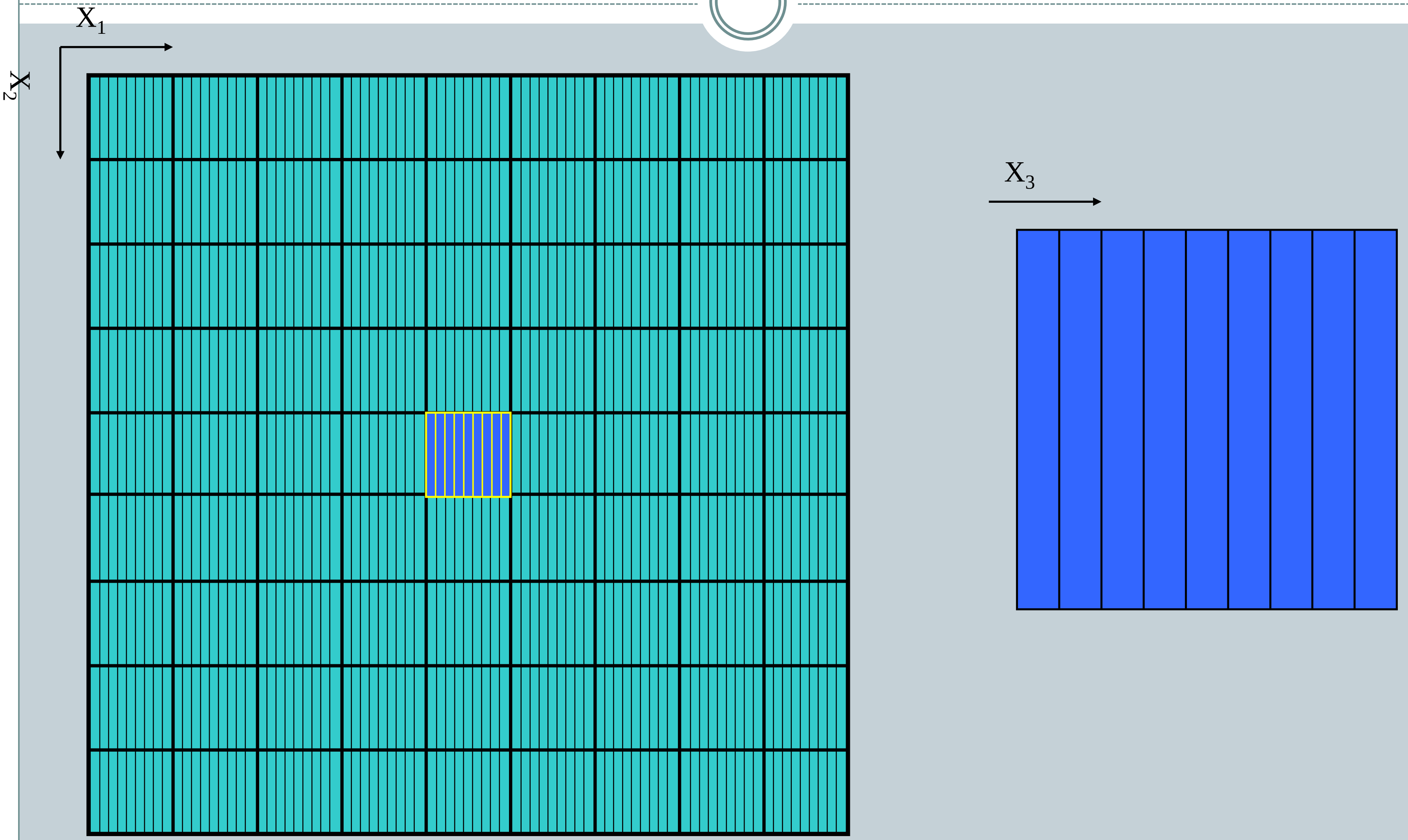
	Mn	Ni	Co	IZNUS %	HV
b_{oo}	3.62008	3.32643	3.08157	89.3840	52.512
Z_1	1.38234	1.36054	1.34503	4.37340	-0.5155
Z_2	0.08241	-0.60414	-.59063	24.1471	35.5936
Z_3	0.48683	-1.01095	-1.0057	-1.50069	2.18833
Z_4	-0.2733	0 .20965	0.1962	-1.35690	-11.716
Z_1^2	-0.4892	0.26593	0.26269	-13.3486	-
$Z_1 Z_2$	0.3625	-0.02813	-0.0175	-2.96520	-
$Z_1 Z_3$	-0.1913	0.04688	0.04625	-.400862	-
$Z_1 Z_4$	0.02375	0.17813	0.17375	3.47138	-
Z_2^2	-0.01135	0.26593	0.26269	-15.8863	-2.00780
$Z_2 Z_3$	0.01749	0.34687	0.34500	-5.64812	-0.2500
$Z_2 Z_4$	-0.02249	-0.12187	-0.1150	-9.25062	0.376250
Z_3^2	0.42373	0.404249	0.40354	-15.0181	11.7220
$Z_3 Z_4$	-0.25625	0.065625	0.06125	-1.56167	-
Z_4^2	-0.01387	0.0270057	0.01623	-2.54097	-11.5676
R	0.9350	0.9637	0.9626	0.9939	0.9999
Fisher	4.9631> 2.8677	9.3073 > 2.8677	9.0126 > 2.8677	93.2084 > 2.3764	374.69 > 2.3661

Data base for the numeric experiment

№	Technological factors				Inputs						Outputs	
	Z_1	Z_2	Z_3	Z_4	X_1 Mn	X_1 kod Mn	X_2 Ni	X_2 kod Ni	X_3 Co	X_3 kod Co	%iznust	%otHV
1	0	0	0	0	3,62	-0,014	3,32	-0,445	3,08	-0,440	88,21	52,66
2	0	0	-1	-1	3,56	-0,037	4,62	-0,046	4,37	-0,039	74,06	62,24
3	0	0	1	-1	5,04	0,546	2,47	-0,706	2,23	-0,705	70,88	66,5
4	0	0	1	1	3,98	0,128	3,02	-0,537	2,75	-0,543	68,37	43,18
5	0	0	-1	1	3,52	-0,053	4,91	0,043	4,64	0,045	74,66	38,65
6	-1	0	0	0	1,74	-0,755	2,23	-0,779	1,99	-0,779	70,57	53,21
7	1	0	0	0	4,51	0,337	4,95	0,055	4,68	0,058	79,57	52,12
8	1	0	-1	-1	4,62	0,381	6,03	0,387	5,75	0,390	62,36	61,69
9	1	0	1	-1	5,72	0,815	3,97	-0,245	3,71	-0,244	58,61	65,95
10	1	0	1	1	4,71	0,416	4,87	0,031	4,58	0,026	62,8	42,65
11	1	0	-1	1	4,63	0,385	6,67	0,583	6,37	0,583	69,56	38,1
12	1	-1	1	-1	5,22	0,617	4,39	-0,117	4,12	-0,117	24,83	29,04
13	1	-1	1	1	4,26	0,239	5,54	0,236	5,22	0,226	37,53	5
14	1	-1	-1	1	4,21	0,219	8,03	1,000	7,71	1,000	32,93	0
15	1	-1	-1	-1	4,16	0,199	7,15	0,730	6,86	0,736	7,29	24,31
16	1	-1	0	0	4,06	0,160	5,85	0,331	5,56	0,331	39,4	14,61
17	-1	-1	0	0	2,02	-0,645	3,07	-0,521	2,83	-0,518	23,97	15,7
18	-1	-1	1	-1	3,61	-0,018	1,88	-0,887	1,65	-0,885	8,47	30,15
19	-1	-1	1	1	2,55	-0,436	2,31	-0,755	2,06	-0,757	17,96	6,09
20	-1	-1	-1	1	1,74	-0,755	4,99	0,067	4,73	0,073	12,49	1,09
21	-1	-1	-1	-1	1,78	-0,740	4,82	0,015	4,56	0,020	0	25,4
22	-1	1	0	0	1,46	-0,866	1,92	-0,874	1,69	-0,872	79,96	86,76
23	-1	1	1	-1	3,13	-0,207	1,66	-0,954	1,43	-0,953	79,96	100
24	-1	1	1	1	1,98	-0,661	1,61	-0,969	1,37	-0,972	42,15	77,4
25	-1	1	-1	1	1,12	-1,000	2,91	-0,571	2,66	-0,571	59,26	73,34
26	-1	1	-1	-1	1,23	-0,957	3,22	-0,475	2,96	-0,477	83,78	96,2
27	1	1	0	0	4,94	0,507	4,58	-0,058	4,34	-0,048	84,52	85,67
28	1	1	1	-1	6,19	1,000	4,07	-0,215	3,83	-0,207	67,26	98,91
29	1	1	1	1	5,14	0,586	4,73	-0,012	4,46	-0,011	52,85	76,31
30	1	1	-1	1	5,02	0,538	5,83	0,325	5,57	0,334	70,9	72,5
31	1	1	-1	-1	5,05	0,550	5,43	0,202	5,18	0,213	82,21	95,12

№	Technological factors				Imputs						Outputs	
	Z_1	Z_2	Z_3	Z_4	X_1 Mn	X_1 kod Mn	X_2 Ni	X_2 kod Ni	X_3 Co	X_3 kod Co	%iznust	%otHV
32	-1	0	1	-1	3,39	-0,105	1,51	-1,000	1,28	-1,000	55,7	67,05
33	-1	0	1	1	2,28	-0,542	1,7	-0,942	1,45	-0,947	46,61	43,73
34	-1	0	-1	1	1,44	-0,874	3,69	-0,331	3,43	-0,331	51,93	39,20
35	-1	0	-1	-1	1,52	-0,842	3,75	-0,313	3,5	-0,309	58,57	62,79
36	1	-0.5	0	0	4,29	0,250	5,33	0,172	5,05	0,173	62,81	33,86
37	1	-0.5	1	-1	5,48	0,720	4,11	-0,202	3,85	-0,201	41,15	47,99
38	1	-0.5	1	1	4,48	0,325	5,14	0,113	4,83	0,104	50,96	24,31
39	1	-0.5	-1	1	4,42	0,302	7,28	0,770	6,97	0,770	52,17	19,55
40	1	-0.5	-1	-1	4,39	0,290	6,52	0,537	6,24	0,543	36,4	43,49
41	-1	-0.5	0	0	1,88	-0,700	2,59	-0,669	2,35	-0,667	50,7	34,95
42	-1	-0.5	1	-1	3,51	-0,057	1,62	-0,966	1,41	-0,960	37,4	49,08
43	-1	-0.5	1	1	2,42	-0,487	1,94	-0,868	1,68	-0,876	34,05	25,40
44	-1	-0.5	-1	1	1,6	-0,811	4,27	-0,153	4,01	-0,151	36,2	20,64
45	-1	-0.5	-1	-1	1,65	-0,791	4,22	-0,169	3,98	-0,160	31,18	44,59
46	-1	0.5	0	0	1,605	-0,809	2,01	-0,847	1,78	-0,844	76,4	70,48
47	-1	0.5	1	-1	3,27	-0,152	1,52	-0,997	1,29	-0,997	70,78	84,02
48	-1	0.5	1	1	2,14	-0,598	1,59	-0,975	1,34	-0,981	45,62	61,06
49	-1	0.5	-1	1	1,28	-0,937	3,23	-0,472	2,98	-0,471	56,01	56,77
50	-1	0.5	-1	-1	1,38	-0,897	3,42	-0,414	3,17	-0,412	70,9	80,00
51	1	0.5	0	0	4,73	0,424	4,7	-0,021	4,45	-0,014	81,87	69,39
52	1	0.5	1	-1	5,96	0,909	3,95	-0,252	3,71	-0,244	64,62	82,92
53	1	0.5	1	1	4,92	0,499	4,74	-0,009	4,45	-0,014	60,67	59,96
54	1	0.5	-1	1	4,85	0,471	6,19	0,436	5,9	0,437	73,24	55,67
55	1	0.5	-1	-1	4,84	0,467	5,66	0,273	5,41	0,285	75,14	78,90
56	1	0.75	0	0	4,84	0,467	4,63	-0,043	4,38	-0,036	82,19	77,65
57	-1	0.75	0	0	1,53	-0,838	1,95	-0,865	1,72	-0,863	78,12	78,75
58	-1	-0.75	0	0	1,95	-0,673	2,81	-0,601	2,57	-0,599	39,6	25,45
59	1	-0.75	0	0	4,17	0,203	5,57	0,245	5,29	0,247	52,1	24,36
60	1	-0.25	0	0	4,4	0,294	5,13	0,110	4,86	0,114	69,65	43,11
61	-1	-0.25	0	0	1,81	-0,728	2,39	-0,730	2,16	-0,726	59,9	44,21
62	1	0.25	0	0	4,62	0,381	4,81	0,012	4,55	0,017	79,68	60,88

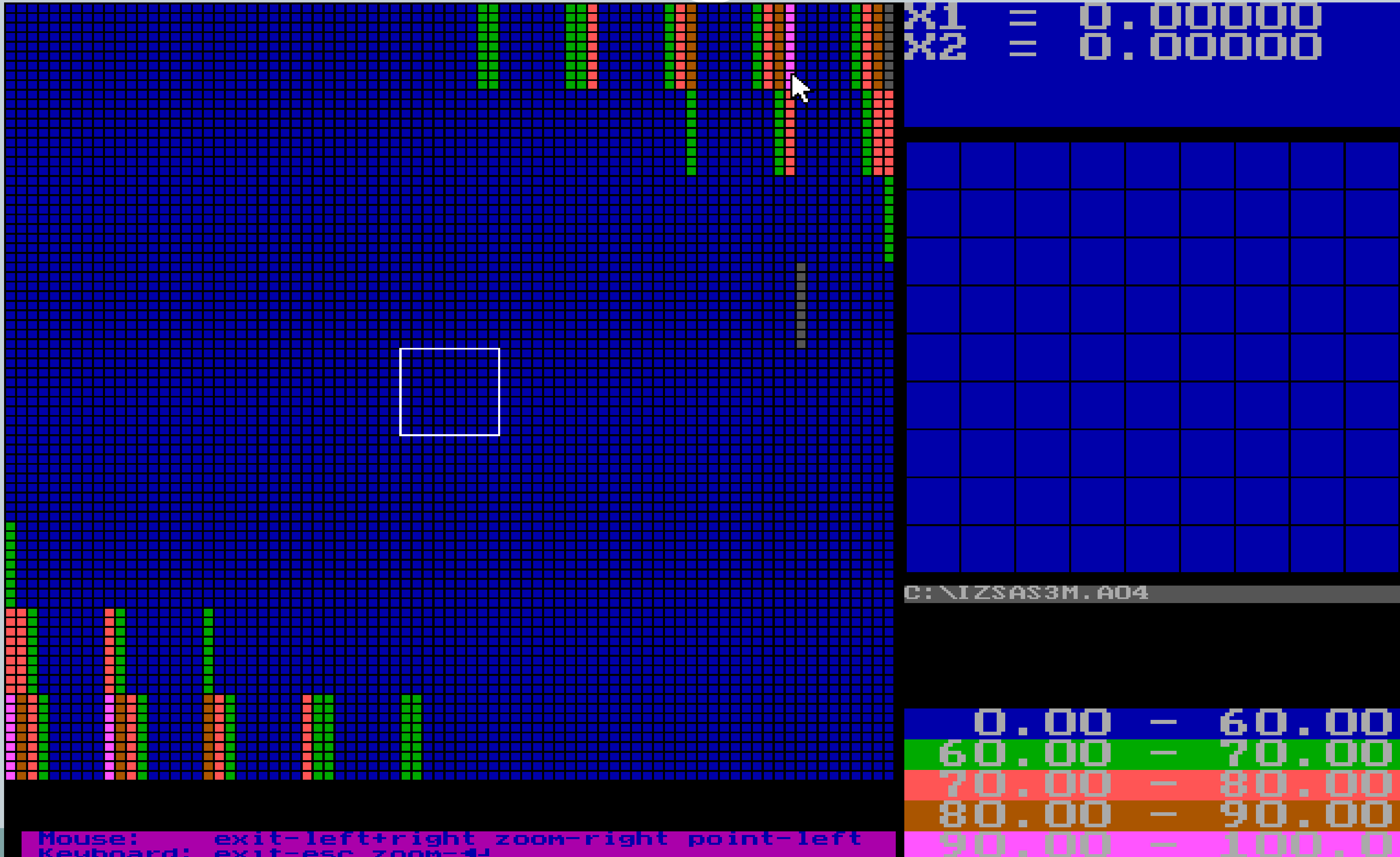
Schematic presentation of images with three parameters



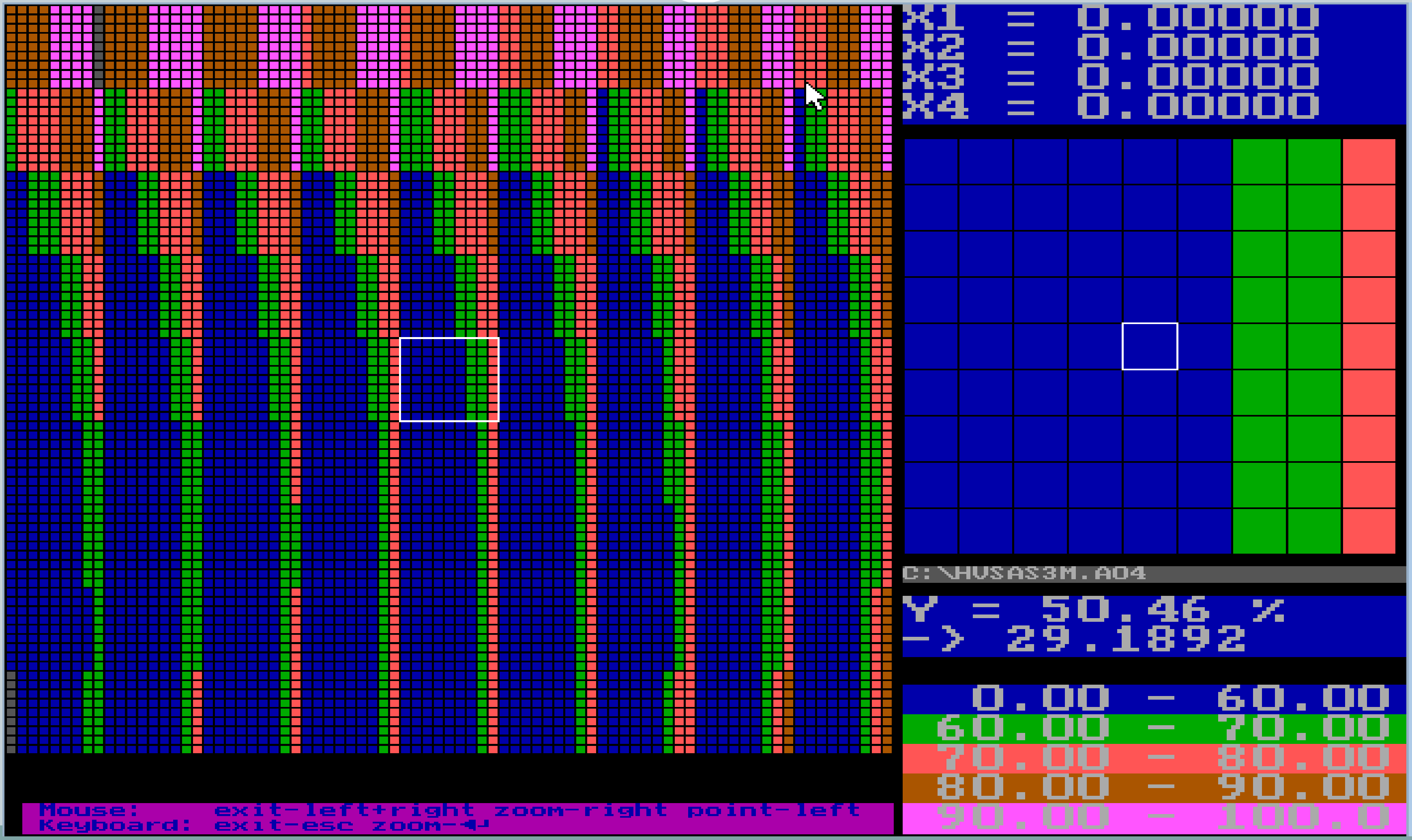
Models of the relation between the percentage of the elements and the normed values of the properties

	Y1(1) % IZNSUS	Y1(2) % IZNSUS	Y2(1) % HV	Y2(2) % HV
b_{00}	57.0685	58.2145	29.1892	22.4887
X_1	19.3710	25.2347	37.3009	41.8051
X_2	-94.6340	-405.350	-1257.39	-2023.96
X_3	78.3287	378.959	1226.38	1984.43
X_1^2	-12.7748	-32.8400	27.0079	55.4727
$X_1 X_2$	-2292.65	-1510.59	194.361	306.132
$X_1 X_3$	2351.06	1605.56	-135.159	-228.941
X_2^2	3479.11	2434.96	661.906	962.981
$X_2 X_3$	-3510.64	-2478.63	-674.971	-974.088
X_3^2	-	-	-	-
$X_1^2 X_2$	-	468.639	-	3604.57
$X_1^2 X_3$	-	-527.256	-	-3560.16
$X_1 X_2 X_3$	-	67.7922	-	13.6093
R	0.6038	0.6576	0.7205	0.7415
Fisher	3.8019 > 2.1261	3.4628 > 1.9977	7.1530 > 2.1261	5.5522 > 1.9977

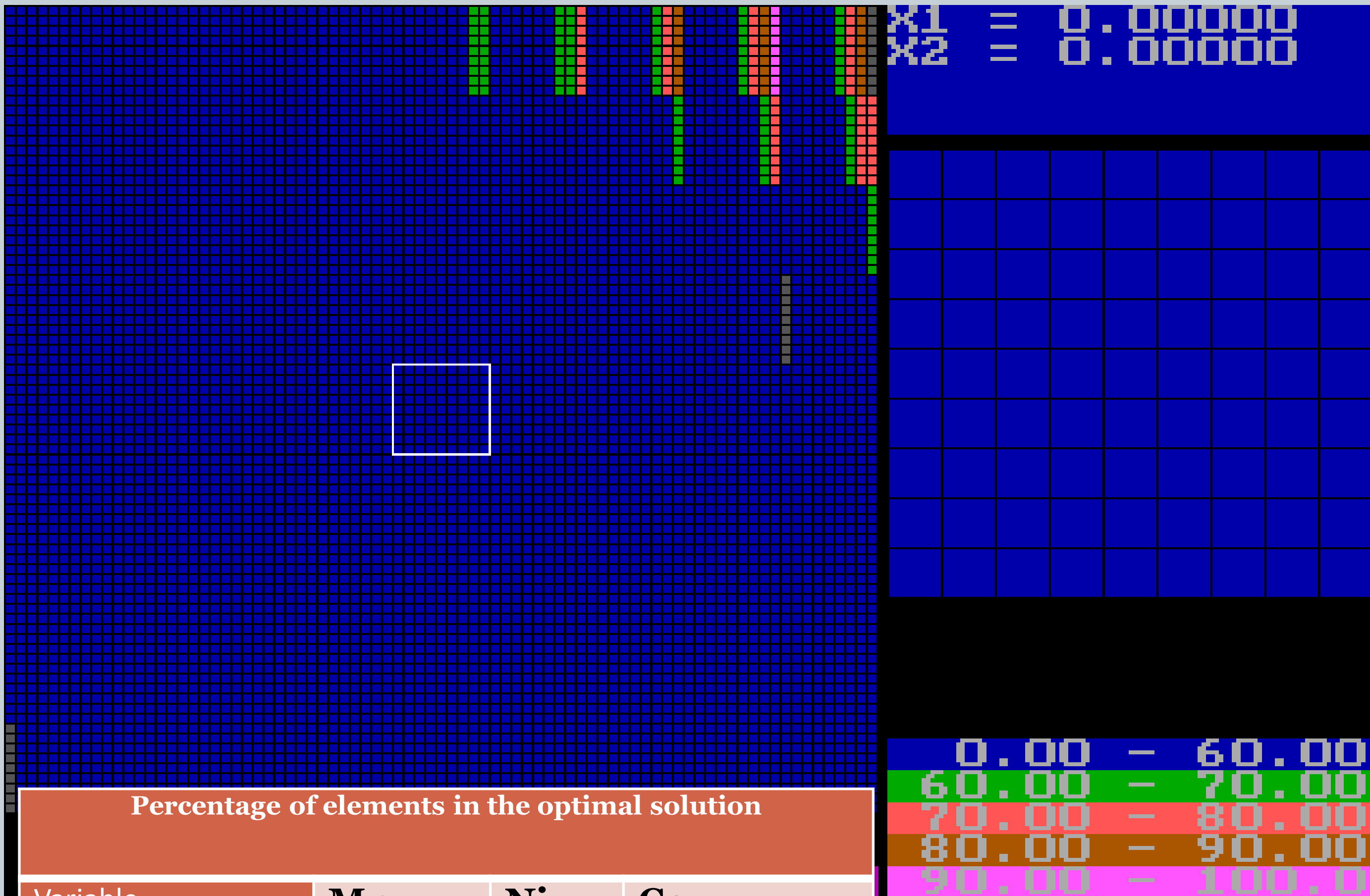
Distribution of the normed wear resistance relative to varying the three elements in the coating



Distribution if normed hardness relative to varying the three elements



Solution of the optimization problem to determine the quantity of Mn, Ni and Co for maximal wear and hardness

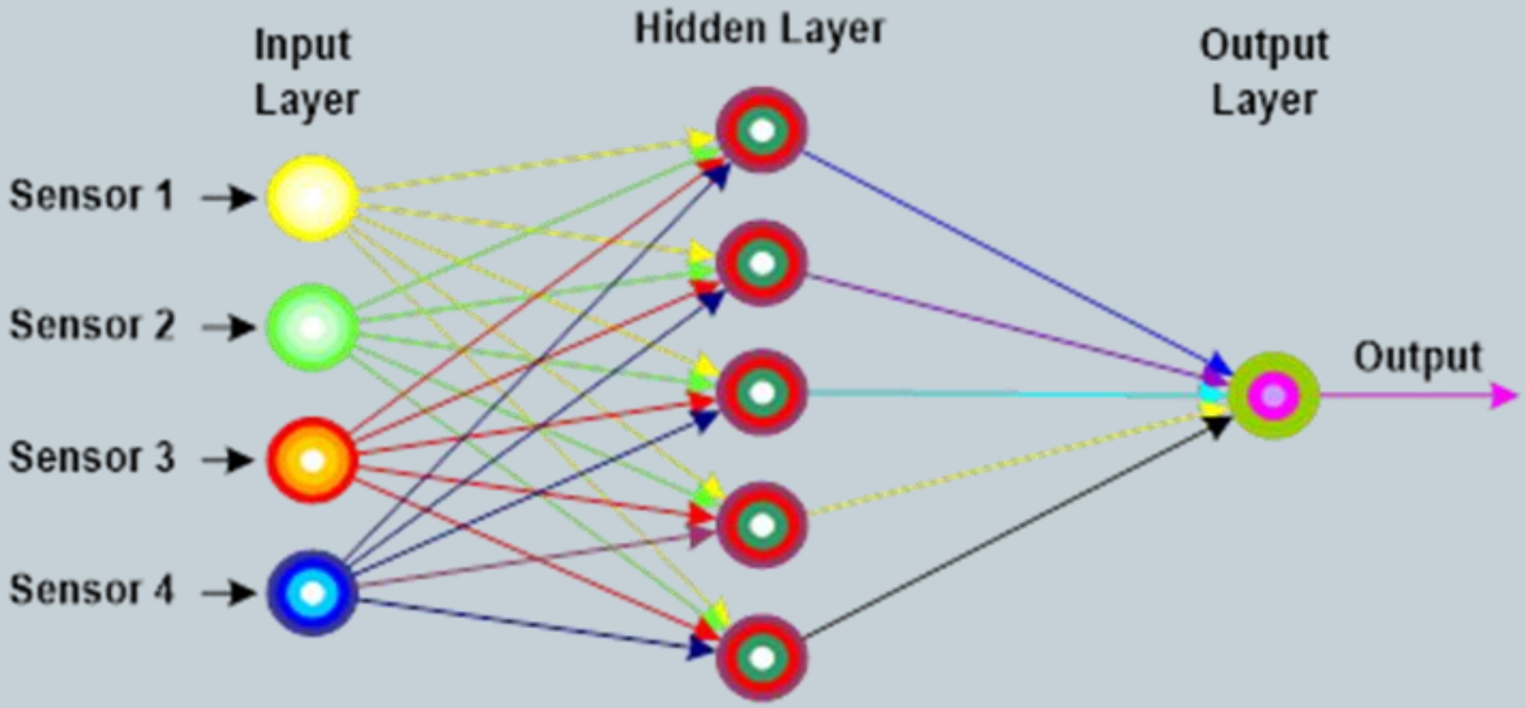


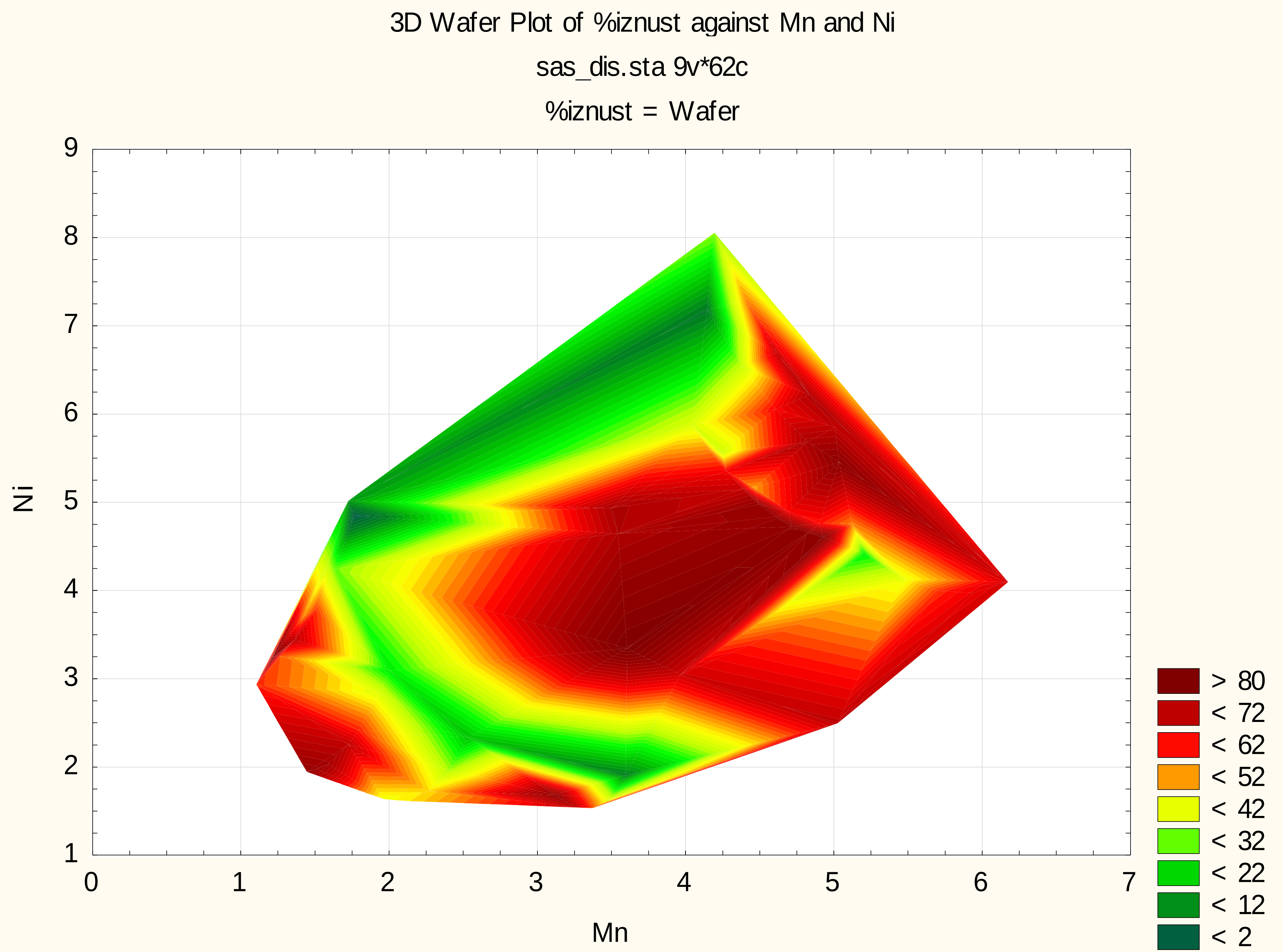
Percentage of elements in the optimal solution

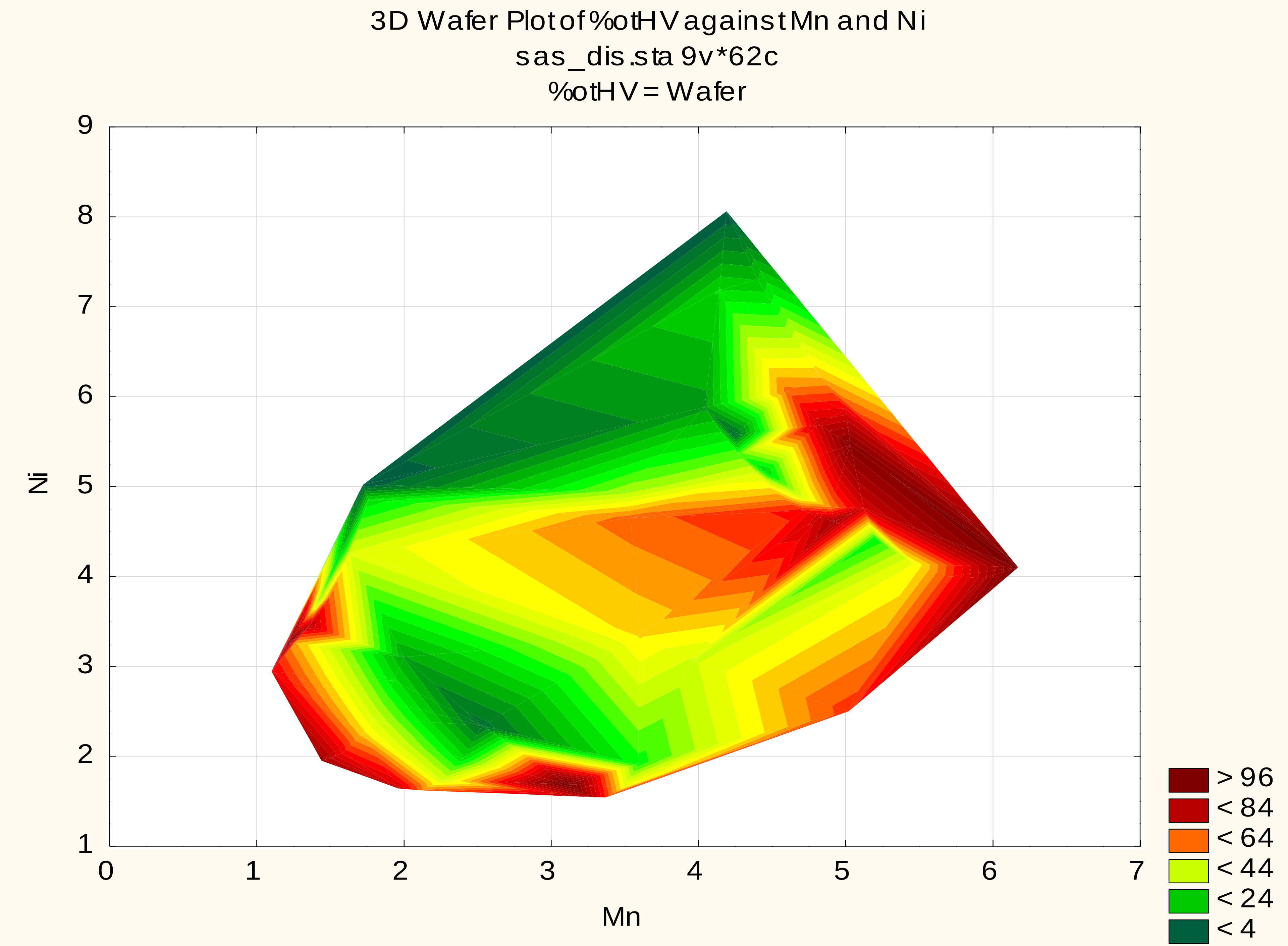
Variable	Mn	Ni	Co
Coded	+1	-1	+1
Real	6.19	1.61	7.71

Parallel numeric modeling with ANNs

Modeling with artificial 'neural' networks type MLP has been performed. A justification of the choice is made with neural models for approximation of the composition as a function of the mechanical and exploitation properties.



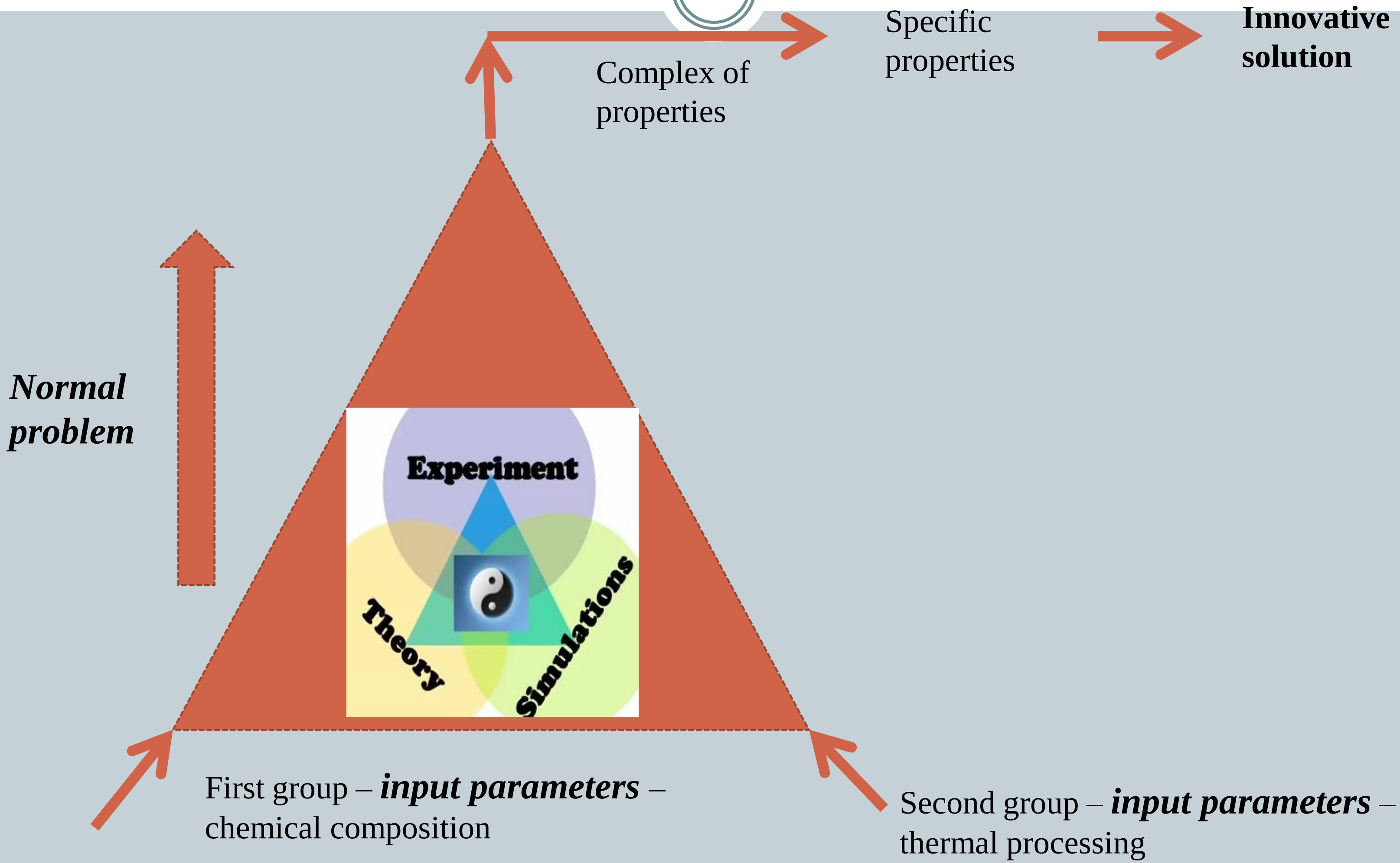

3D Wafer Plot of %iznust against Mn and Ni
sas_dis.sta 9v*62c
%iznust = Wafer
Ni
Mn
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
> 80
< 72
< 62
< 52
< 42
< 32
< 22
< 12
< 2


3D Wafer Plot of %otHV against Mn and Ni
sas_dis.sta 9v*62c
%otHV = Wafer
Ni
Mn
0
1
2
3
4
5
6
7
1
2
3
4
5
6
7
8
9
> 96
< 84
< 64
< 44
< 24
< 4

Architecture of Neural Networks

№	Network type	Approximated parameter	R -training	R -test	R-validation	Activation functions	
						Hidden layer	Output layer
1.	MLP 2-10-1		0,939653	0,939653	0,939653	Hyperbolic tangent	Logistic
2.	MLP 2-8-1	HV	0,951379	0,934230	0,632198	Hyperbolic tangent	Exponent

Summary of activities following from my second thesis for research on contract No. 1256/27.04.15.

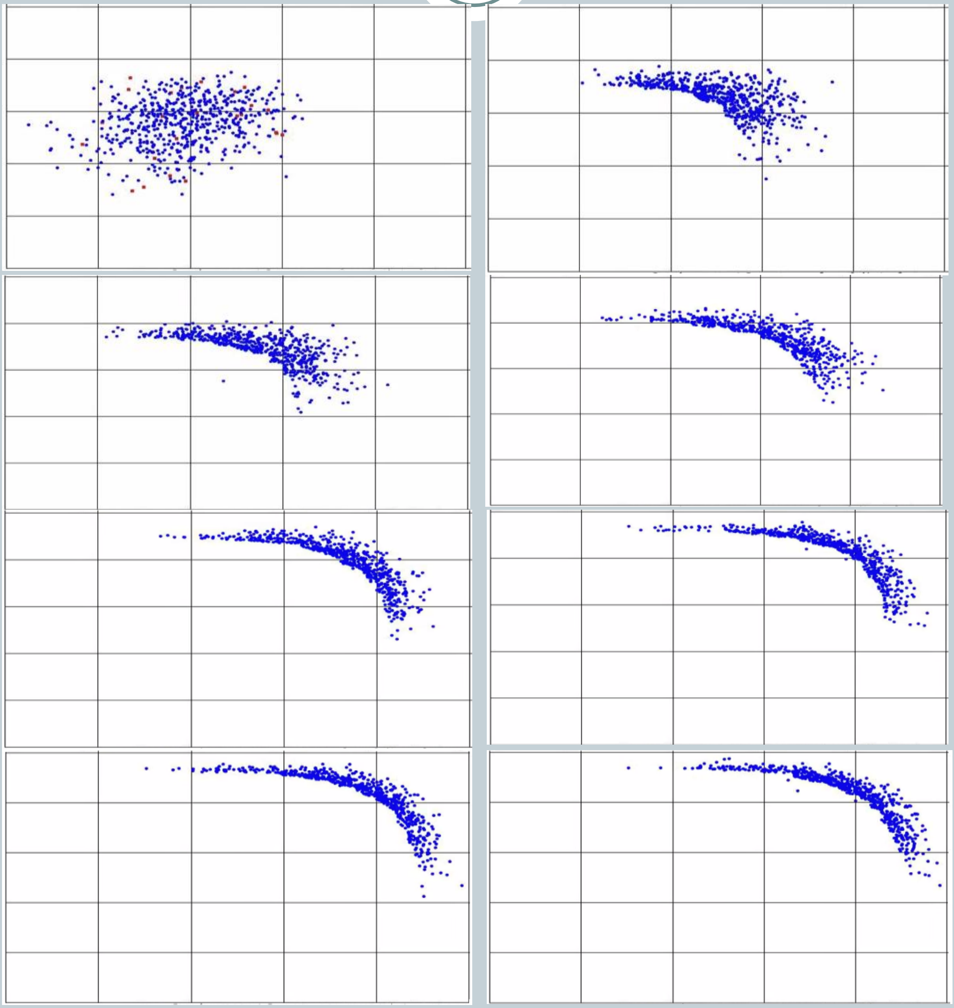


We have accumulated experience and software is made to define the impact of separate components in the composition on its final properties. This task is named for short metal design and it is directly related to my second thesis. The goal for it was to elaborate tools that can allow independently of the used data base to improve the properties for which the conditions of the improvement are defined.

- A **DEB-based program** has been developed which defines the complex of properties as a Pareto front.

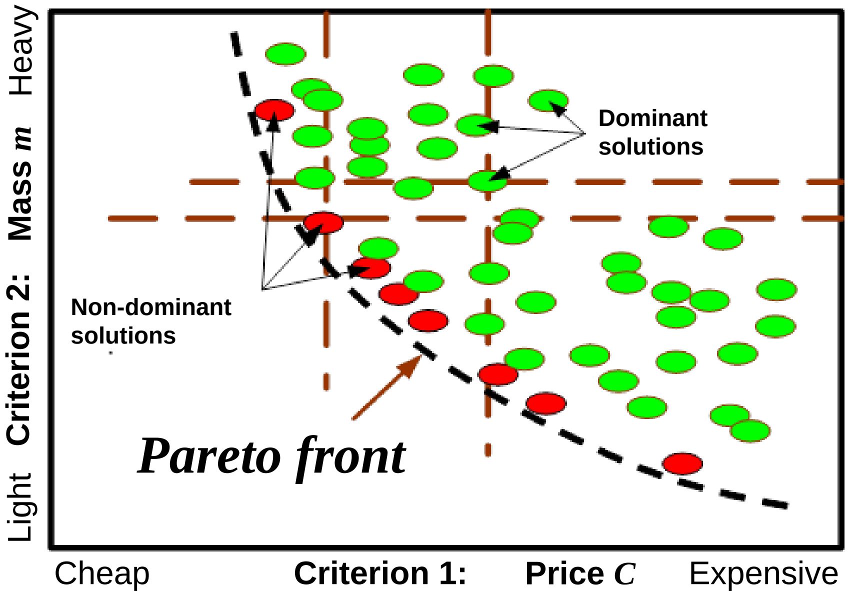
- This approach works not in the space of the parameters but in the space of the criteria.

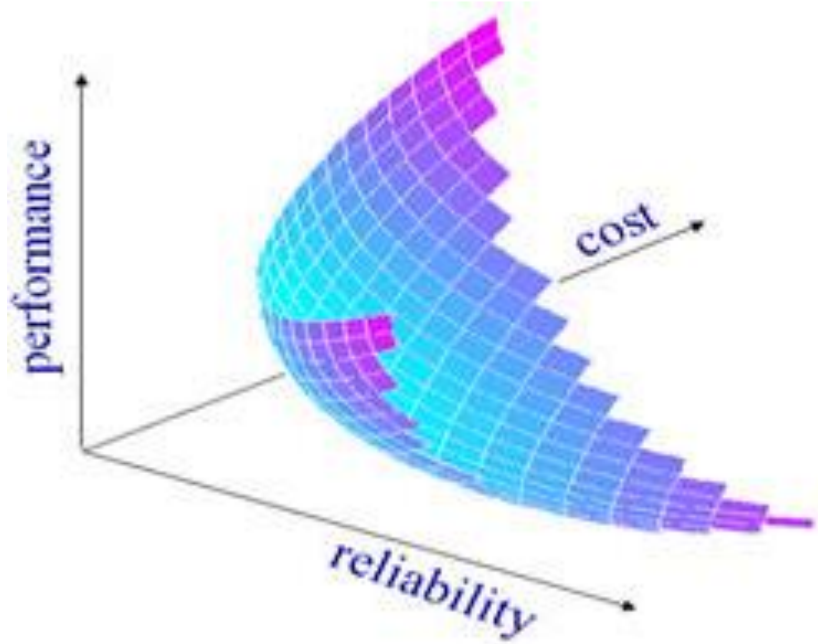
Exhaustive iterations to determine Pareto front of the explored mechanical indicators



With the help of ANN approximation and applying the popular DEB algorithm it is possible to determine Pareto front – the front of the optimal solutions for the relation between the best ratio of mechanical indicators and the implicit correspondence of the related chemical composition.

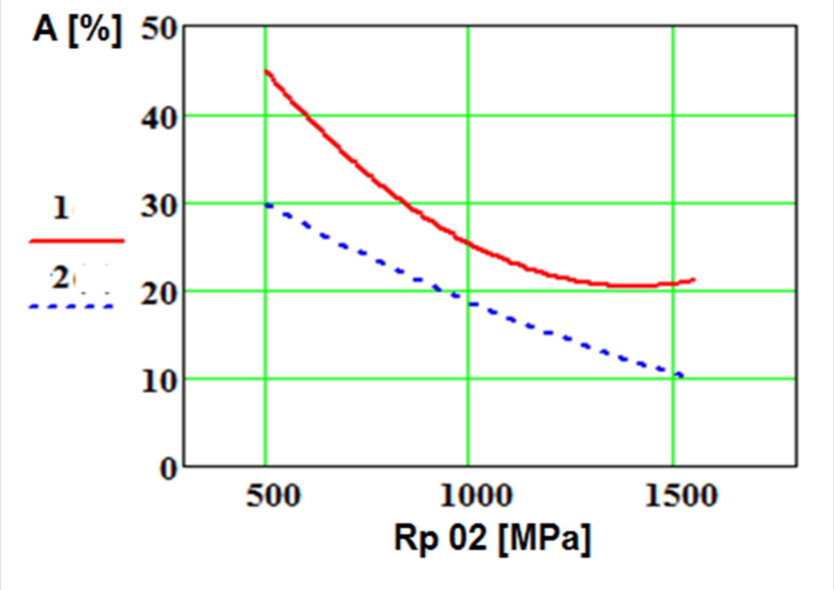
Implicit compromise between the chemical composition, the cost, strength and plasticity characteristics

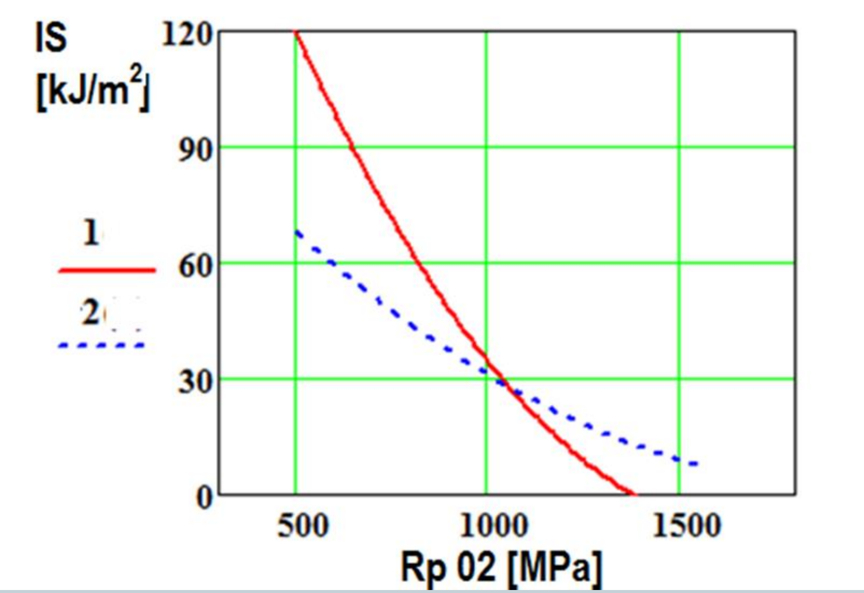




The chemical composition is implicitly present so we have an implicit compromise between the price, … . Pareto front in the plane degrades to a surface and sometimes to a hyper-surface.

Pareto fronts of the investigated mechanical characteristics for titanium alloys with two types of thermal processing





1) Annealed state

2) Tempered state

Here we have the determined by us Pareto fronts for the data base delivered by the University of Belfast for titanium-based alloys, from two heat treatments. It proves again that hardened by tempering alloys have lower plasticity.

Y_1 –/R_{p02}/	№	Y2% n - /A/	Y2% n - /A/	Y1– / R_{p02}/	№	Y2% n - /A/	Y2% n - /A/
1046,17	1,0	88,44		1027,97	41,0	94,48	
1045,95	2,0		88,56	1028,34	42,0		94,25
1124,94	3,0	64,54		1225,17	43,0	39,42	
1121,61	4,0		66,05	1225,69	44,0		40,24
1186,96	5,0	48,30		1347,01	45,0	16,86	
1185,41	6,0		49,53	1348,16	46,0		17,51
1166,16	7,0	53,50		1315,63	47,0	21,84	
1164,16	8,0		54,78	1313,49	48,0		23,11
1067,39	9,0	81,64		1035,59	49,0	91,93	
1075,46	10,0		79,41	1033,55	50,0		92,55
1087,48	11,0	75,45		1090,31	51,0	74,60	
1090,67	12,0		74,88	1090,67	52,0		74,88
1186,53	13,0	48,41		1151,84	53,0	57,22	
1185,41	14,0		49,53	1150,59	54,0		58,27
1080,26	15,0	77,65		1224,98	55,0	39,46	
1090,67	16,0		74,88	1223,96	56,0		40,62
1097,66	17,0	72,40		1379,09	57,0	12,38	
1098,28	18,0		72,66	1378,66	58,0		13,13
1297,53	19,0	24,97		1188,16	59,0	48,01	
1296,73	20,0		26,05	1188,41	60,0		48,80
1352,78	21,0	16,01		1382,23	61,0	11,98	
1351,64	22,0		16,98	1384,56	62,0		12,35
1174,79	23,0	51,31		1147,76	63,0	58,30	
1176,23	24,0		51,77	1150,59	64,0		58,27
1014,95	25,0	98,93		1173,72	65,0	51,58	
1012,41	26,0		99,55	1176,23	66,0		51,77
1111,52	27,0	68,35		1262,54	67,0	31,57	
1113,91	28,0		68,20	1262,37	68,0		32,57
1149,09	29,0	57,95		1221,14	69,0	40,32	
1150,59	30,0		58,27	1219,22	70,0		41,67
1169,75	31,0	52,58		1367,75	71,0	13,90	
1168,89	32,0		53,59	1367,74	72,0		14,64
1153,50	33,0	56,78		1192,87	73,0	46,87	
1154,70	34,0		57,20	1189,05	74,0		48,65
1054,71	35,0	85,67		1170,47	75,0	52,40	
1045,95	36,0		88,56	1172,35	76,0		52,73
1150,38	37,0	57,60		1220,66	77,0	40,42	
1150,59	38,0		58,27	1219,22	78,0		41,67
1011,85	39,0	100,00		1288,40	79,0	26,62	
1011,06	40,0		100,00	1287,38	80,0		27,76

Determined Pareto base

The method of calculation includes determining 80 solutions from Pareto front with high mechanical indicators and also achieved via economic alloying.

Experimental data base for the relation between the composition and the properties of the explored titanium alloys

Y1- Rp	Y2 - A	Al	Mo	Sn	Zr	Cr	Fe	V	Si	O	Sum 1	Sum 2
1046,17	20,18	7,04	4,73	4,26	0,40	0,23	2,93	3,71	0,28	0,13	23,71	9,08
1045,95	33,47	4,20	5,13	4,76	0,46	2,77	2,54	6,61	0,37	0,12	26,96	14,97
1124,94	18,04	3,25	3,37	3,94	1,38	2,91	3,72	1,62	0,21	0,17	20,58	9,29
1121,61	25,78	4,73	3,08	0,32	3,09	0,11	1,81	6,58	0,04	0,09	19,85	12,86
1186,96	16,60	6,96	3,57	4,45	0,90	4,88	2,89	0,37	0,44	0,14	24,60	9,73
1185,41	20,13	5,03	2,12	1,53	3,05	6,46	0,60	0,80	0,30	0,08	19,98	12,44
1166,16	17,06	3,97	2,11	6,42	0,24	2,06	3,95	5,51	0,30	0,20	24,76	9,93
1164,16	21,93	6,20	0,95	9,78	5,94	0,23	4,32	2,56	0,09	0,11	30,18	9,68
1067,39	19,57	0,48	2,25	3,14	2,46	2,14	3,28	3,41	0,12	0,15	17,42	10,26
1075,46	30,34	2,60	2,89	1,84	4,72	2,91	0,63	3,57	0,25	0,16	19,57	14,08
1087,48	19,02	4,47	0,50	2,24	8,27	1,42	0,30	0,83	0,22	0,23	18,48	11,02
1090,67	28,79	1,62	1,48	0,44	1,25	0,06	2,95	11,26	0,34	0,07	19,47	14,05
1186,53	16,60	2,41	1,70	5,05	0,75	3,98	3,99	5,32	0,28	0,22	23,70	11,75
1185,41	20,13	5,03	2,12	1,53	3,05	6,46	0,60	0,80	0,30	0,08	19,98	12,44
1080,26	19,21	5,22	6,29	3,44	1,40	2,21	0,82	2,02	0,24	0,23	21,86	11,92
1090,67	28,79	1,62	1,48	0,44	1,25	0,06	2,95	11,26	0,34	0,07	19,47	14,05
1097,66	18,75	3,01	7,71	6,68	0,20	3,38	3,63	0,69	0,42	0,23	25,93	11,97
1098,28	28,04	7,78	2,56	8,69	2,37	0,35	1,47	9,16	0,46	0,24	33,09	14,44
1297,53	14,51	7,22	2,86	8,42	0,06	7,06	2,13	2,05	0,01	0,10	29,92	12,04
1296,73	12,11	5,84	2,45	1,22	0,64	2,56	2,67	10,90	0,26	0,17	26,71	16,55
1352,78	13,71	4,96	1,10	4,08	0,06	10,73	0,92	0,25	0,42	0,19	22,71	12,14
1351,64	9,01	4,76	6,91	0,46	6,59	5,52	3,54	1,15	0,23	0,16	29,33	20,17
1174,79	16,86	4,72	2,07	1,86	4,10	0,46	3,16	5,52	0,15	0,15	22,18	12,14
1176,23	20,90	2,48	3,65	1,21	0,03	5,86	2,08	3,34	0,12	0,11	18,88	12,88
1014,95	21,11	2,12	9,04	1,11	1,12	0,94	3,22	1,06	0,04	0,09	18,74	12,16
1012,41	37,23	2,03	0,10	1,12	2,23	0,98	3,66	3,27	0,24	0,12	13,75	6,58
1111,52	18,39	4,43	7,61	2,13	1,39	3,28	1,69	0,04	0,26	0,21	21,05	12,33
1113,91	26,51	1,12	1,95	9,94	7,09	1,01	3,83	2,71	0,01	0,17	27,82	12,75
1149,09	17,46	3,40	2,42	4,16	3,62	2,95	4,98	3,46	0,02	0,08	25,09	12,45
1150,59	23,12	1,49	2,44	3,26	3,04	2,22	4,20	4,28	0,31	0,19	21,44	11,98
1169,75	16,98	4,05	2,22	7,64	3,53	2,19	4,72	4,58	0,30	0,09	29,31	12,52
1168,89	21,52	3,71	2,40	4,62	6,01	0,23	4,84	4,01	0,38	0,22	26,42	12,65
1153,50	17,35	2,19	1,05	1,72	3,77	2,05	2,87	5,70	0,17	0,20	19,74	12,58
1154,70	22,75	2,14	2,92	0,22	3,66	0,38	4,09	6,96	0,22	0,21	20,81	13,92
1054,71	19,93	4,68	9,65	1,90	0,40	0,76	2,91	2,05	0,11	0,11	22,56	12,85
1045,95	33,47	4,20	5,13	4,76	0,46	2,77	2,54	6,61	0,37	0,12	26,96	14,97
1150,38	17,43	3,14	0,55	1,94	8,13	2,56	1,60	1,76	0,19	0,07	19,95	13,02
1150,59	23,12	1,49	2,44	3,26	3,04	2,22	4,20	4,28	0,31	0,19	21,44	11,98

Y1- Rp	Y2 - A	Al	Mo	Sn	Zr	Cr	Fe	V	Si	O	Sum 1	Sum 2
1011,85	21,21	1,46	6,45	7,86	1,05	1,12	1,59	4,73	0,21	0,23	24,71	13,35
1011,06	37,38	4,30	8,75	7,69	1,98	5,43	0,27	3,73	0,49	0,21	32,85	19,88
1027,97	20,72	4,33	1,52	5,47	0,98	2,68	2,20	8,30	0,34	0,07	25,89	13,48
1028,34	35,42	1,83	7,38	2,65	5,21	2,68	1,58	2,79	0,48	0,14	24,73	18,05
1225,17	15,80	1,52	0,83	3,59	1,31	7,39	3,00	4,26	0,26	0,21	22,35	13,78
1225,69	16,96	0,06	6,61	5,54	4,90	0,33	3,72	7,61	0,24	0,23	29,23	19,44
1347,01	13,79	4,68	3,49	0,35	0,13	9,67	3,13	0,53	0,36	0,22	22,57	13,83
1348,16	9,19	4,39	14,47	3,44	5,77	0,15	2,70	2,56	0,08	0,25	33,81	22,94
1315,63	14,23	4,20	3,05	1,70	1,13	8,44	1,38	1,25	0,07	0,09	21,30	13,87
1313,49	11,10	6,88	0,39	7,83	0,34	5,26	2,83	8,33	0,14	0,09	32,10	14,34
1035,59	20,49	1,91	5,69	7,36	0,66	0,72	4,27	7,01	0,45	0,13	28,20	14,09
1033,55	34,84	7,86	10,26	9,12	1,48	1,73	0,61	3,05	0,16	0,19	34,46	16,52
1090,31	18,94	3,56	0,21	7,71	0,21	6,47	0,70	7,22	0,09	0,08	26,25	14,10
1090,67	28,79	1,62	1,48	0,44	1,25	0,06	2,95	11,26	0,34	0,07	19,47	14,05
1151,84	17,39	5,61	2,49	7,14	1,51	3,73	2,23	6,51	0,28	0,12	29,61	14,23
1150,59	23,12	1,49	2,44	3,26	3,04	2,22	4,20	4,28	0,31	0,19	21,44	11,98
1224,98	15,81	0,04	0,51	8,79	4,08	9,41	4,95	0,30	0,24	0,20	28,52	14,29
1223,96	17,09	1,65	7,43	4,51	0,93	5,01	3,25	4,76	0,06	0,10	27,71	18,14
1379,09	13,39	6,53	5,61	0,42	0,12	7,87	4,92	0,74	0,27	0,06	26,55	14,34
1378,66	7,69	4,30	2,70	4,38	7,07	3,98	3,57	9,43	0,45	0,23	36,10	23,18
1188,16	16,57	3,00	4,38	1,16	1,26	6,88	3,47	1,83	0,11	0,23	22,32	14,35
1188,41	19,88	5,16	4,47	3,07	4,47	4,86	1,54	1,27	0,34	0,14	25,32	15,07
1382,23	13,35	7,72	1,39	2,30	1,25	4,32	3,95	7,40	0,42	0,24	28,99	14,37
1384,56	7,42	5,34	5,25	8,19	2,85	10,10	1,33	7,29	0,12	0,19	40,66	25,50
1147,76	17,49	1,16	3,82	10,67	1,61	4,94	2,87	4,01	0,03	0,16	29,28	14,38
1150,59	23,12	1,49	2,44	3,26	3,04	2,22	4,20	4,28	0,31	0,19	21,44	11,98
1173,72	16,89	1,61	2,09	3,59	4,36	3,70	2,57	4,32	0,11	0,13	22,47	14,47
1176,23	20,90	2,48	3,65	1,21	0,03	5,86	2,08	3,34	0,12	0,11	18,88	12,88
1262,54	15,10	5,34	2,88	4,53	2,15	5,55	2,69	3,93	0,23	0,06	27,36	14,52
1262,37	14,33	6,10	0,67	3,65	0,65	1,97	1,41	12,94	0,32	0,18	27,91	16,25
1221,14	15,88	5,91	3,69	6,12	4,35	4,32	2,57	2,22	0,40	0,22	29,80	14,59
1219,22	17,45	3,14	2,02	5,52	6,07	0,97	3,90	5,55	0,17	0,09	27,44	14,61
1367,75	13,53	7,99	2,16	0,45	7,69	2,89	4,47	1,86	0,19	0,21	27,91	14,61
1367,74	8,21	1,93	0,12	2,06	8,06	4,07	4,85	1,84	0,44	0,07	23,44	14,09
1192,87	16,47	1,02	1,15	2,74	4,71	3,20	2,76	5,61	0,20	0,21	21,60	14,67
1189,05	19,83	7,94	6,83	4,01	9,17	0,28	3,92	1,38	0,01	0,24	33,79	17,66
1170,47	16,96	3,98	4,93	0,91	8,00	1,43	3,31	0,35	0,42	0,15	23,47	14,70
1172,35	21,22	7,76	8,26	1,01	1,02	2,65	2,31	0,94	0,27	0,12	24,34	12,86
1220,66	15,89	7,21	2,26	1,77	6,57	0,34	2,38	5,60	0,46	0,08	26,66	14,77
1219,22	17,45	3,14	2,02	5,52	6,07	0,97	3,90	5,55	0,17	0,09	27,44	14,61

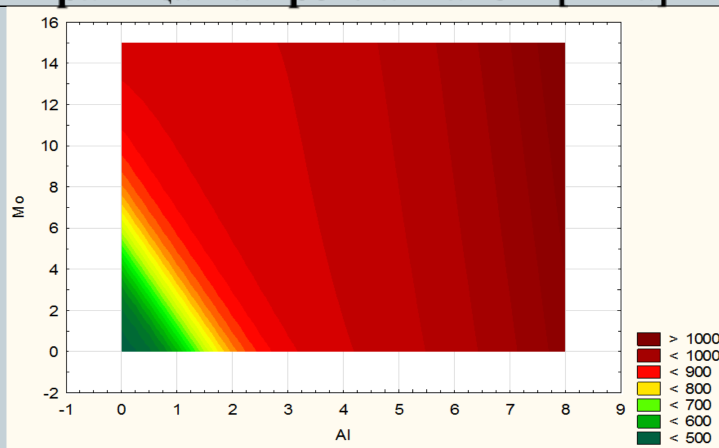
General view of the regression models for the influence of the chemical composition on the mechanical properties

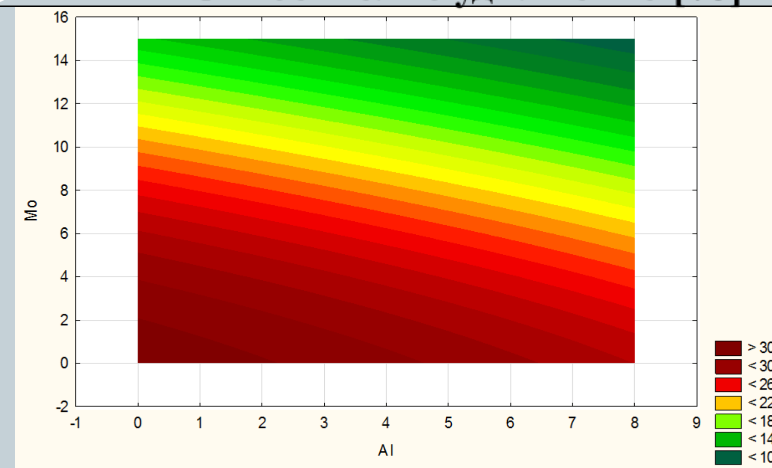
Rp_{02} = 1211.88 + 51.5221 Al - 24.9734 Mo - 80.7796 Sn + 96.9246 Zr + 209.828 Cr + 80.3385 Fe + 72.0976 V - 21.4625 Si + 40.3190 O - 6.81555 Al^2 - 106.347 Al Mo - 69.9600 Al Sn - 43.6439 Al Zr + 15.4261 Al Cr -61.9896 Al Fe -81.5665 Al V + 10.3925 Al Si + 47.3631 Al O + 31.7825 Mo^2 - 24.5042 Mo Sn - 19.5766 Mo Zr - 43.8777 Mo Cr - 34.0499 Mo Fe - 70.3951 Mo V - 51.3807 Mo Si + 60.8373 Mo O + 6.35824 Sn^2 - 62.3299 Sn Zr -49.0562 Sn Cr + 47.2030 Sn Fe - 84.9186 Sn V + 7.34492 Sn Si + 47.5112 Sn O + 44.0214 Zr^2 -39.5834 Zr Cr - 34.9639 Zr Fe + 19.4983 Zr V + 34.0014 Zr Si + 1.40613 Zr O + 109.626 Cr^2 - 26.3554 C Fe + 12.6771 Cr V + 0.829980 Cr SI - 24.8476 Cr O - 75.0358 Fe^2 + 3.91375 Fe V + 25.5956 Fe Si - 67.2523 Fe O - 6.09390 V^2 + 19.2299 V Si + 17.1889 V O -51.7804 Si^2 +19.0743 Si O -38.5409 O^2

A = 43.4377- 12.4873 Al + 5.83605 Mo + 16.1346 Sn - 26.5634 Zr - 41.6628 Cr -11.3614 Fe - 12.2634 V + 9.45284 Si - 7.32094 O + 4.99262 Al^2 + 32.8537 Al Mo + 13.9749 Al Sn + 6.60931 Al Zr + 2.81458 Al Cr + 24.7026 Al Fe + 26.9275 Al V- 4.94533 Al Si - 7.11438 Al O - 8.72509 Mo^2 +3.37836 Mo Si + 1.36551 Mo Zr + 13.8703 Mo Cr + 13.3358 Mo Fe + 18.9816 Mo V + 9.02304 Mo Si -3.70434 Mo O + 2.60378 Sn^2 +7.48801 Sn Zr + 3.57374 Sn Cr- 13.2362 Sn Fe + 18.1995 Sn V +2.45297 Sn Si-7.84135 Sn O - 12.5869 Zr^2 + 11.2109 Zr Cr + 11.6078 Zr Fe - 1.06720 Zr V - 5.39692 Zr Si + 3.89560 Zr O - 11.8927 Cr^2 + 18.2370 Cr Fe + 12.9706 Cr V + 0.427527 Cr Si + 8.14636 Cr O + 22.7628 Fe^2 + 14.6460 Fe V - 10.9786 Fe Si + 18.1532 Fe O + 1.46032 V^2 -4.26022 V Si - 6.8052 V O + 14.9821 Si^2 - 5.02353 Si O + 1.21278 O^2

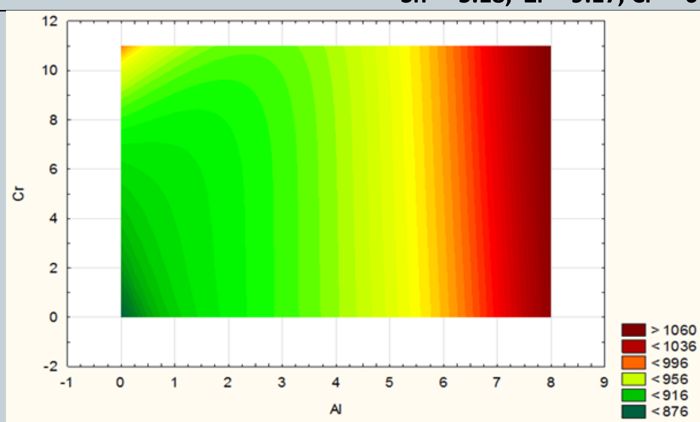
Visualizing the optimal solution for the metallurgical design of titanium alloys in annealed state

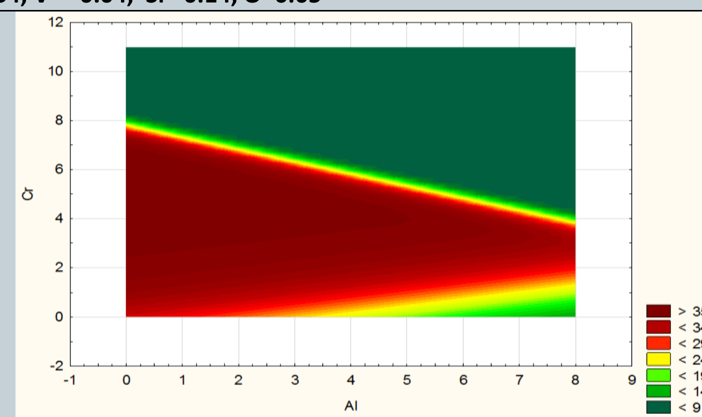
Граница на провлачване в [MPa] | **Относително удължение [%]**





Sn = 5.18, Zr = 9.17, Cr = 0.06, Fe = 1.34, V = 0.04, Si =0.14, O=0.05

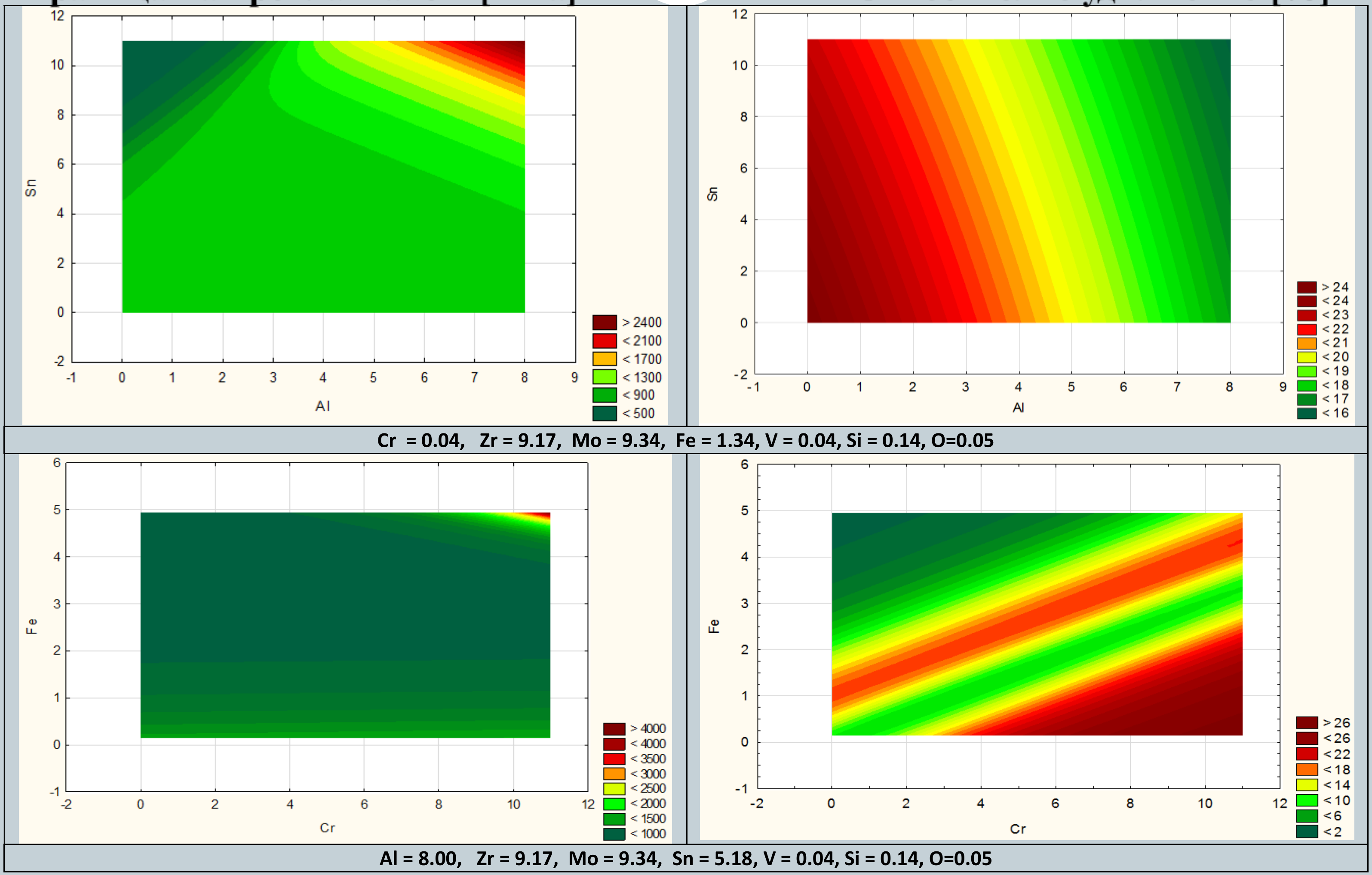




Sn = 5.18, Zr = 9.17, Mo = 9.34, Fe = 1.34, V = 0.04, Si = 0.14, O=0.05

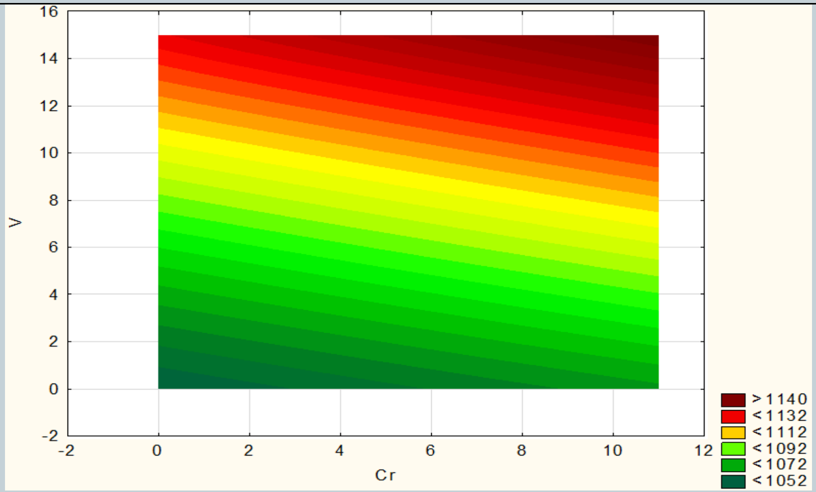
Visualizing the optimal solution for the metallurgical design of titanium alloys in annealed state

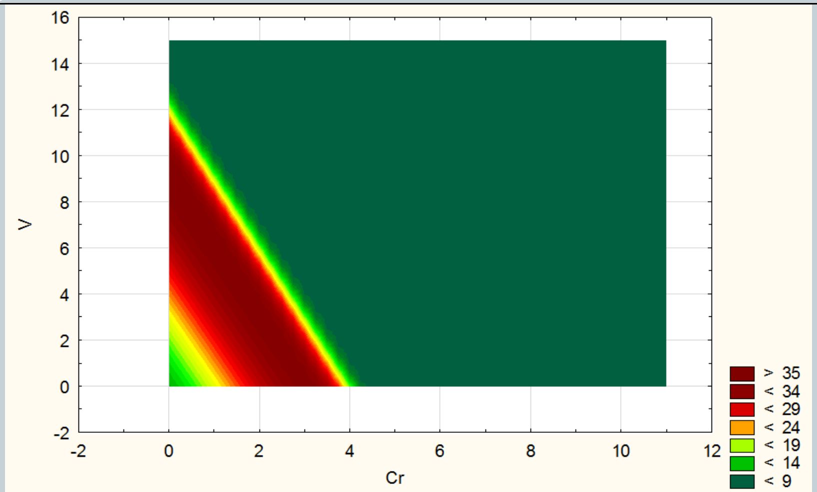
Граница на провлачване в [MPa] **Относително удължение [%]**



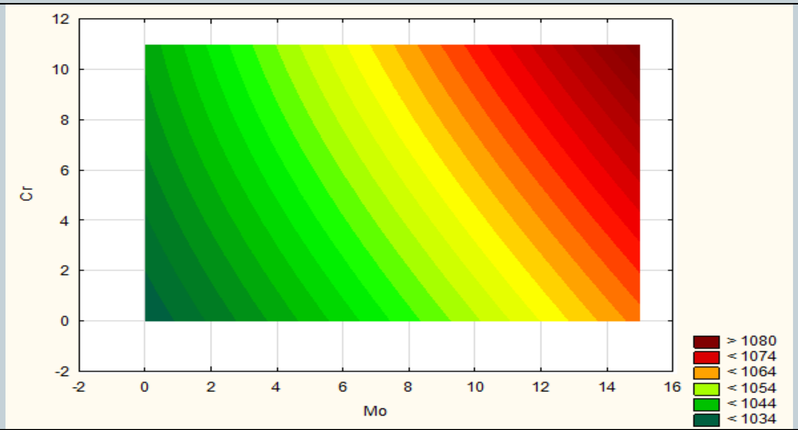
Visualizing the optimal solution for the metallurgical design of titanium alloys in annealed state

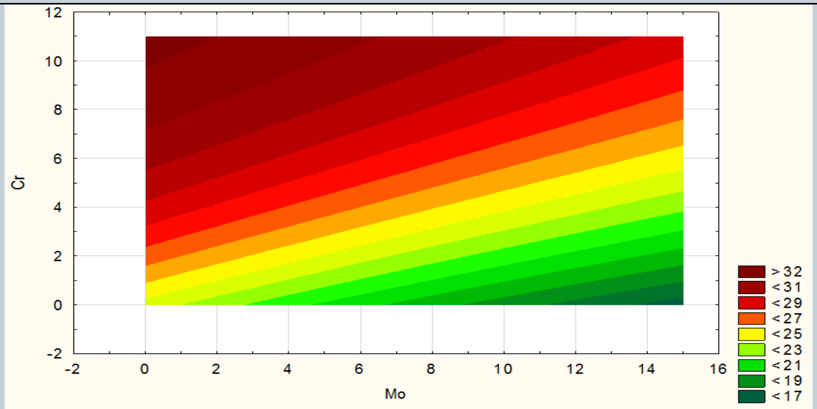
Yield strength [MPa] **Relative elongation [%]**





Al = 8.00, Zr = 9.17, Mo = 9.34, Sn = 5.18, Fe= 1.34, Si = 0.14, O=0.05





Al = 8.00, Zr = 9.17, Fe = 1.34, Sn = 5.18, V = 0.04, Si = 0.14, O=0.05

CONCLUTIONS

https://www.researchgate.net/publication/316889741_Principle_of_operation_and_applications_of_the_MADMML_software

https://www.researchgate.net/publication/309823792_GENERALIZED_ALGORITHM_FOR_NUMERICAL_ANALYSIS_AND_MULTICRITERIA_OPTIMIZATION_OF_MULTIPARAMETRIC_REGRESSION_MODELS

https://www.researchgate.net/publication/265292354_BOOK_with_methods_to_metallurgical_design_alloys_-_httpswwwmorebooksdestoregbbookmaterials-science-effective-solutions-and-technological-variantsisbn978-3-659-22604-5

https://www.researchgate.net/publication/321492511_APPLICATION_OF_CAD_DESIGN_OF_TECHNOLOGICAL_PROCESSES_IN_THE_FIELD_OF_MATERIAL_SCIENCE

The achieved results give grounds for future active international cooperation with scientific and production institutions for which a specific scientific product has been created and tested. The elaborated scientific product is a set of numerical methods beyond the scope of the originally intended application only for metallurgical and metalworking production. The developed methods are evaluated with the benefits of the relevant area. In the references, results have been achieved for saving materials and energy while maintaining the same level of quality indicator. This also indirectly reflects on the environmental protection. The importance of my research has been underpinned by the universality of the approach, and it has been developed for models of regression analysis and the artificial neural networks. Thus, a valuable and up-to-date methodology, thoroughly endorsed in a scientific style, has been apportioned and implemented.


Thank you