Artificial Intelligence [AI] versus Design of Experiments in Rubber Compounding

H-JG Consulting

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Tomorrow‘s machines will „think“ for us – they may even tell us what to do!

Walter A. Rapetski, European Rubber Journal, March 1983

You can bet that tomorrow's thinking machines will be very similar to today's - old algorithms running on faster computers.

Bart Kosko, in John Brockman, Editor; What to think about machines that think; 2015

Content of this presentation

1. Introduction
2. Tools in Compounding
   - Design of Experiment
   - Compounding and Artificial Intelligence
3. Advantage and Limits
4. Comparison
5. Conclusion

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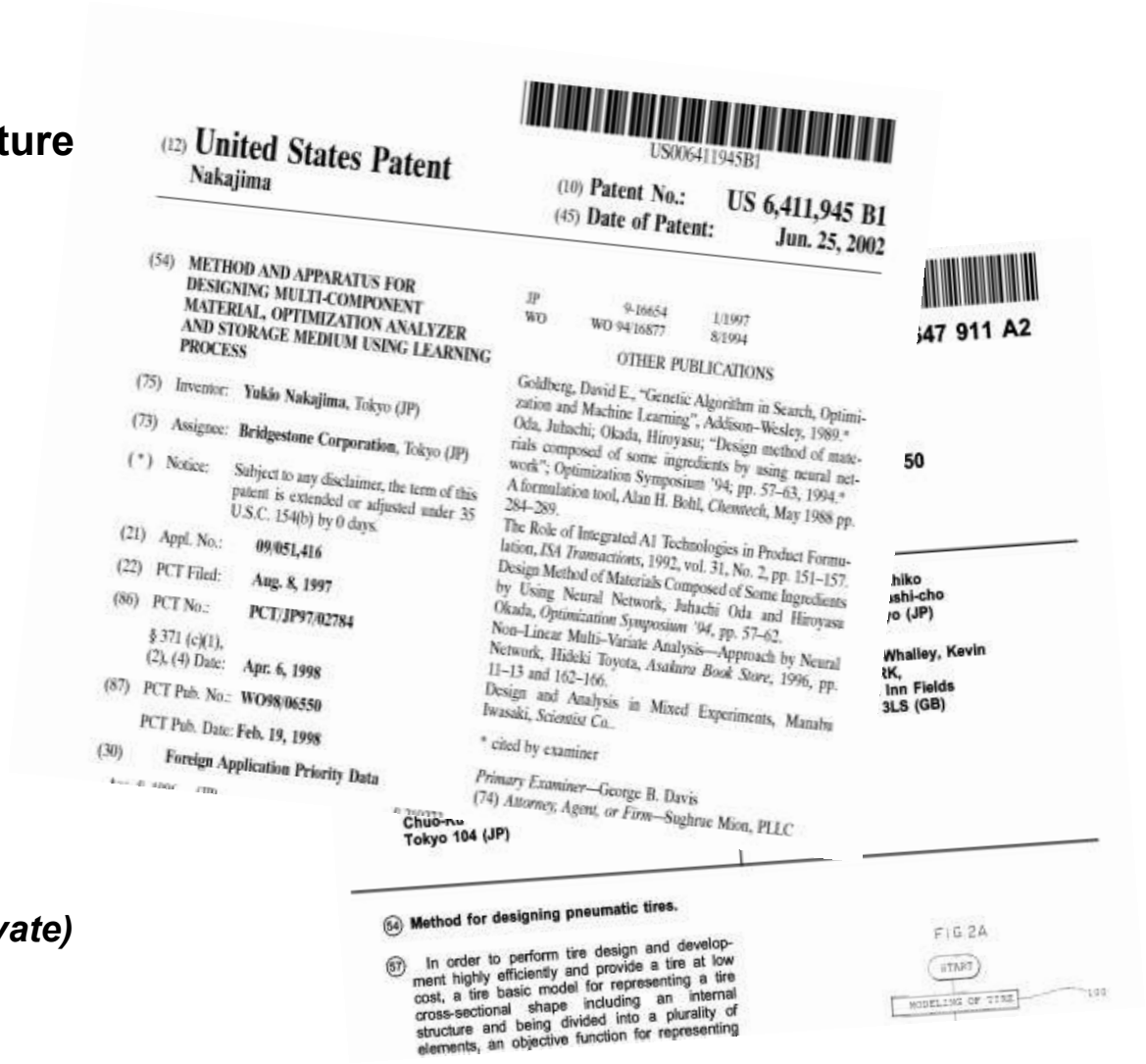
➔ Computer Aided Compound Development in Patent Literature

- **Bridgestone Patent 1994**
  Inventor: Akihiko Abe
- **Bridgestone Patent 2002**

Inventor: Yukio Nakajima

- ***Colour Matching Patents from BASF, CyanAmid, DuPONT***
- ***Empirical DoE Patent: Honeywell***
- ***Recipe Library Search and Comparison CombiChem, GE, Hunt (Private)***



(12) **United States Patent**
Nakajima

US006411945B1

(10) **Patent No.: US 6,411,945 B1**
(45) **Date of Patent: Jun. 25, 2002**

(54) **METHOD AND APPARATUS FOR DESIGNING MULTI-COMPONENT MATERIAL, OPTIMIZATION ANALYZER AND STORAGE MEDIUM USING LEARNING PROCESS**

(75) Inventor: **Yukio Nakajima**, Tokyo (JP)

(73) Assignee: **Bridgestone Corporation**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/051,416**

(22) PCT Filed: **Aug. 8, 1997**

(86) PCT No.: **PCT/JP97/02784**
§ 371 (c)(1),
(2), (4) Date: **Apr. 6, 1998**

(87) PCT Pub. No.: **WO98/06550**
PCT Pub. Date: **Feb. 19, 1998**

(30) **Foreign Application Priority Data**

JP 9-16654 1/1997
WO WO 94/16877 8/1994

OTHER PUBLICATIONS

Goldberg, David E., "Genetic Algorithm in Search, Optimization and Machine Learning", Addison-Wesley, 1989.*
Oda, Juhachi; Okada, Hiroyasu; "Design method of materials composed of some ingredients by using neural network"; Optimization Symposium '94; pp. 57–63, 1994.*
A formulation tool, Alan H. Bohl, Chemtech, May 1988 pp. 284–289.
The Role of Integrated AI Technologies in Product Formulation, ISA Transactions, 1992, vol. 31, No. 2, pp. 151–157.
Design Method of Materials Composed of Some Ingredients by Using Neural Network, Juhachi Oda and Hiroyasu Okada, Optimization Symposium '94, pp. 57–62.
Non-Linear Multi-Variate Analysis—Approach by Neural Network, Hideki Toyota, Asakura Book Store, 1996, pp. 11–13 and 162–166.
Design and Analysis in Mixed Experiments, Manabu Iwasaki, Scientist Co.,

* cited by examiner

Primary Examiner—George B. Davis
(74) *Attorney, Agent, or Firm*—Sughrue Mion, PLLC

Chuo-ku
Tokyo 104 (JP)

(54) **Method for designing pneumatic tires.**

(57) In order to perform tire design and development highly efficiently and provide a tire at low cost, a tire basic model for representing a tire cross-sectional shape including an internal structure and being divided into a plurality of elements, an objective function for representing

FIG 2A
START
MODELING OF TIRE

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➔ Definition:
Statistic Experimental Design

- The (statistical) design of experiments (DOE) is **an efficient procedure for planning experiments** so that the data obtained can be analyzed to yield valid and objective conclusions. ... An Experimental Design is the laying out of a detailed experimental plan in advance of doing the experiment.
- Statistic is a formal science, whose methods are applied to a wide variety of natural and engineering sciences. The interpretation of the results only make sense if they have been verified for their plausibility in the context of the intrinsic sciences.
- In engineering, it is often necessary to work with small samples, so the treatment of small samples or series of experiments and the presentation of distribution-independent test procedures is of particular importance.

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An investigation consists of the following steps applied in a **sequential**, **iterative** manner:

HYPOTHESIZE

DESIGN

ANALYZE

The statistic analysis answers the question whether test results are to be considered as random phenomena or may be treated as characteristic.

➔ Definition:
Artificial Intelligence

- The theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages. (google 15.10.21)
- Deep learning, meanwhile, is a subset of machine learning that enables computers to solve more complex problems.
- Neural networks, also known as artificial neural networks (ANNs) or simulated neural networks (SNNs), are a subset of machine learning and are at the heart of deep learning algorithms. Their name and structure are inspired by the human brain, mimicking the way that biological neurons signal to one another.

➔Software Tools in Compound Development

➔Database Oriented: Artificial Intelligence [AI]

- Better utilization of historic compound data base
- Faster results - minimizes efforts and time in development
- Increases creativity through compound simulation

➔Experimentation Oriented: Design of Experiments [DoE]

- Evaluation of New Material without History
- Correlation between effect of factors on responses
- Creates statistically sound knowledge about ingredients and processes

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- **Software Tools in Compound Development**
  - **Experimentation oriented [DoE]**
  - **Input: Factor Variation**
    - **Experiments according DoE systematic**
    - **Testing**
    - **Data treatment: ANOVA, Regression, Correlation between factor variation and response**
  - **Output: Prediction of Recipe, Overlay Contour Plots, Correlation Maps,**

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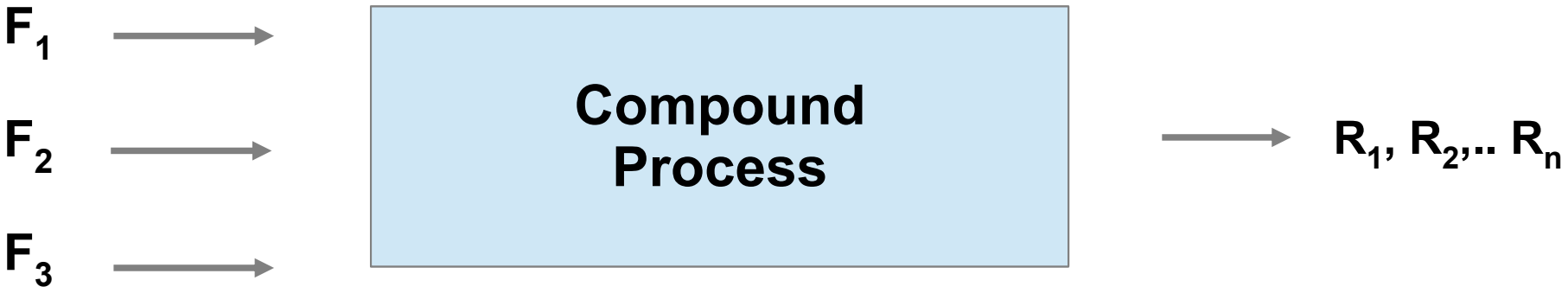
Experimentation: Variation of Factors

Measurements: Responses



Objective of the Experiment is the identification of the factors (F_1,..F_n) type of influence on the responses (R_1,...R_n) and description with mathematical equations for further processing.

ANOVA is used for statistical evaluation.

$$R_{i(1...n)} = f(A_0 + A_1F_1 + ...A_nF_n + ...)$$

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Properties of Compound is determined by Polymer, CB and Oil content and the ratio of CB and Oil.

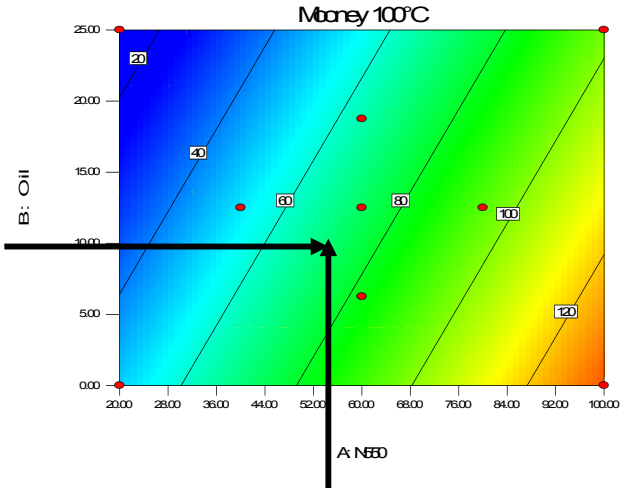
Data of DoE converted into a contour plot

- **CB 550: 55 phr**
- **Oil: 10 phr**

- **Mooney Viscosity: 71 M-Units**
- **Hardness: 60 ° ShA**
- **Tensile: 21 MPa**
- **Elongation: 460 %**
- **C-Set: 28%**

NR Compound

- *SMR 5CV – 100 phr*
- ***CB – Var***
- ***Oil – Var***
- *ZnO – 5 phr*
- *StAc – 1 phr*
- *AO – 1 phr*
- *NR 100 phr*
- *MBTS – 0.6*
- *S – 2.5 phr*



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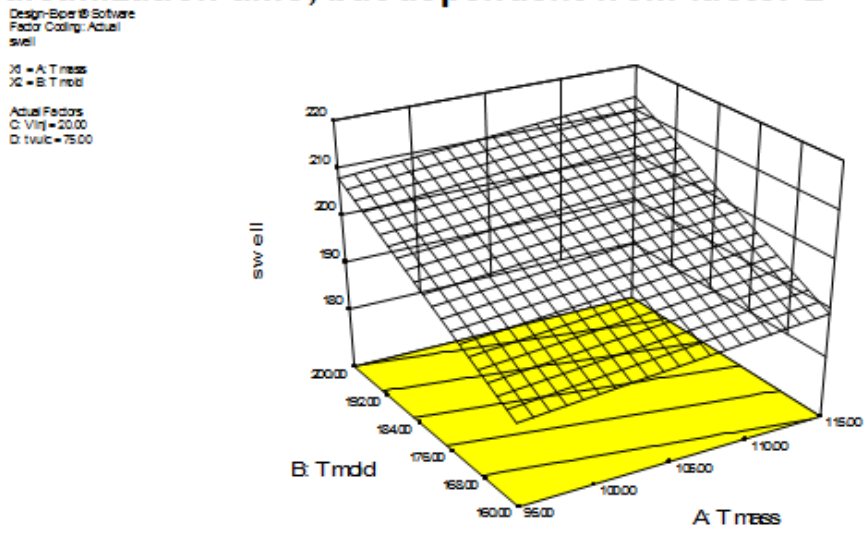
DoE in Processing

- **Example: Operating Window in Injection Molding**
  Statistic Experimental Design (DoE) procedure
  - **Factor 1 = T_M** — **Mass Temperature**
  - **Factor 2 = T_{mold}** — **Mold Temperature**
  - **Factor 3 = v_{inf}** — **Injection Speed**
    (little influence EPDM, but big with NBR)
  - **Factor 4 = t_{vulc}** — **vulcanization time, but dependent from factor 2**

Name	Units	Low	High
T mass	°C	95	115
T mold	°C	160	200
V inj	mm/sec	15	25
t vulc	sec	30	120



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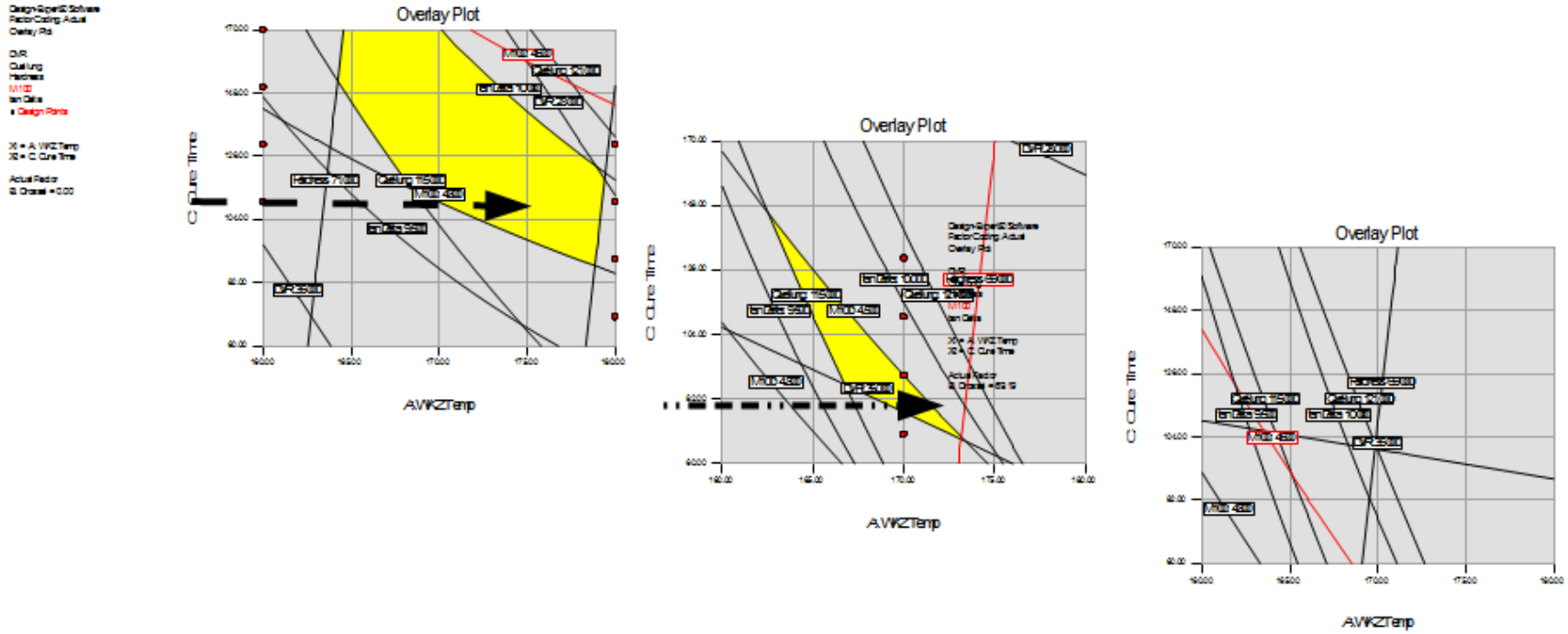
DoE in Processing

- **Example: Operating Window in Injection Molding**
  Resulting operating Window for a NR-72°ShA Compound:
  Dependency of Mass Temperatures (= Nozzle Valve Positions with LWB-EFE)
  - **Nozzle position 0 – open / 40 – half closed / 70 – almost closed**



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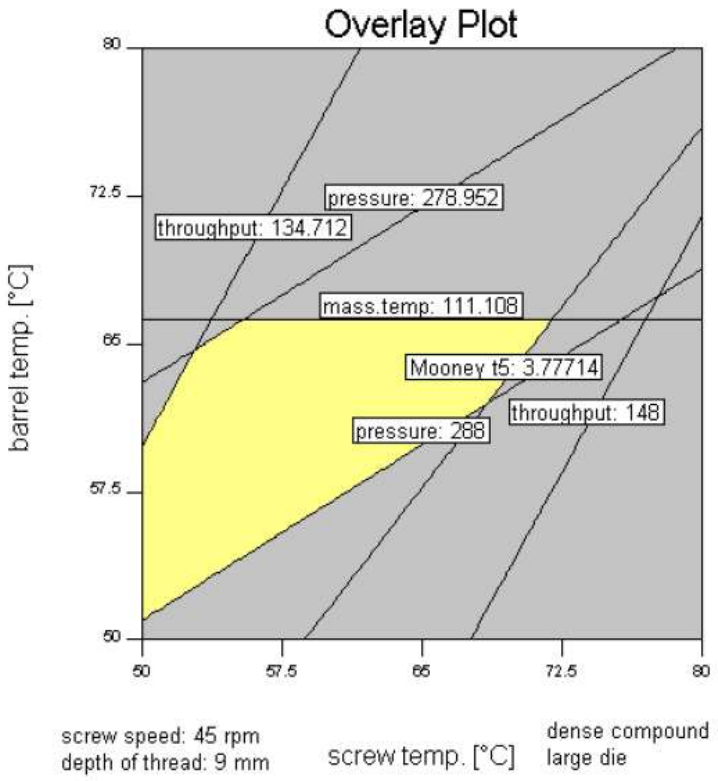
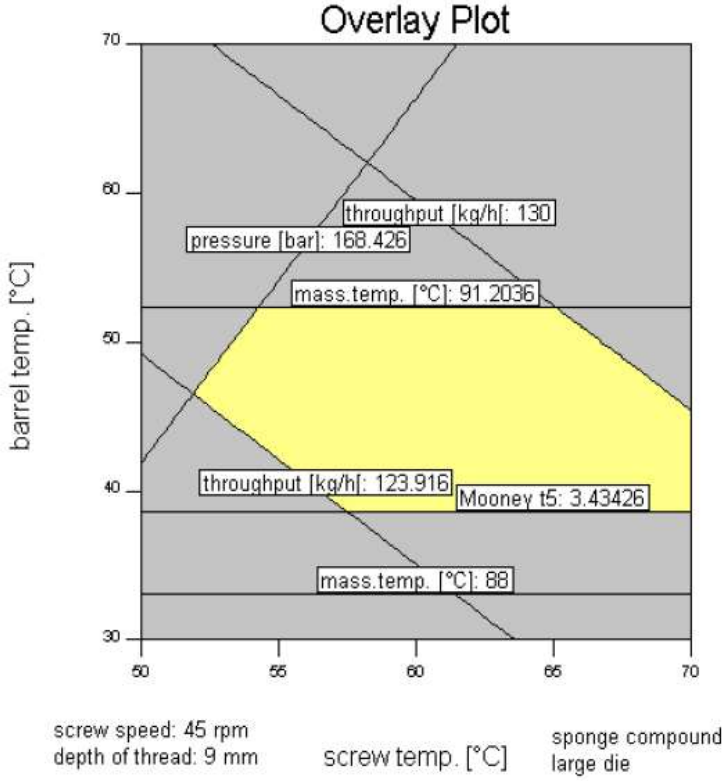
DoE in Processing





Dependency of Operating window in extrusion
On screw [x-axis] and barrel [y-axis] temperature.

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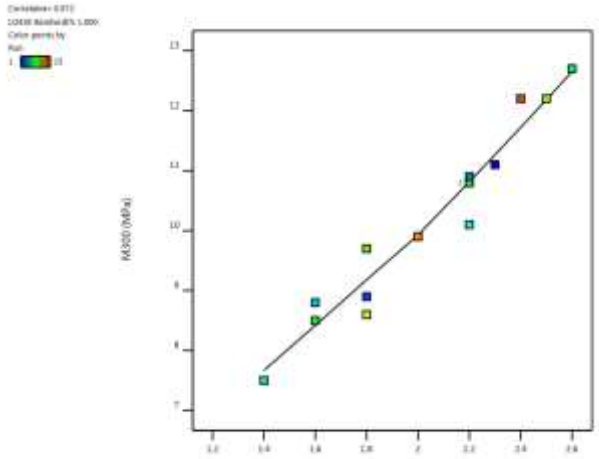
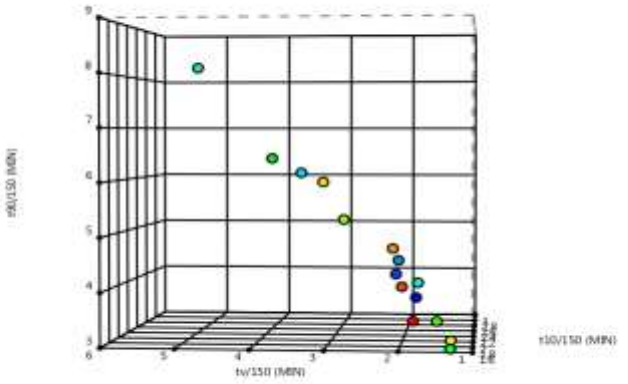
Statistic experimental design software tools in Design Expert®

- Correlation diagrams allowing a first evaluation of the data:
  - Following inherent logic of rubber principles
- Histograms
- Scatter plots

- Further tools are
  - Contour plots
  - Desirability plots, whether target is met / or failed
  - Prediction



Correlation Diagram:
M100 over M300



Correlation Diagram:
t_{10}/150C, T_v 150C, and t_{90}/150C

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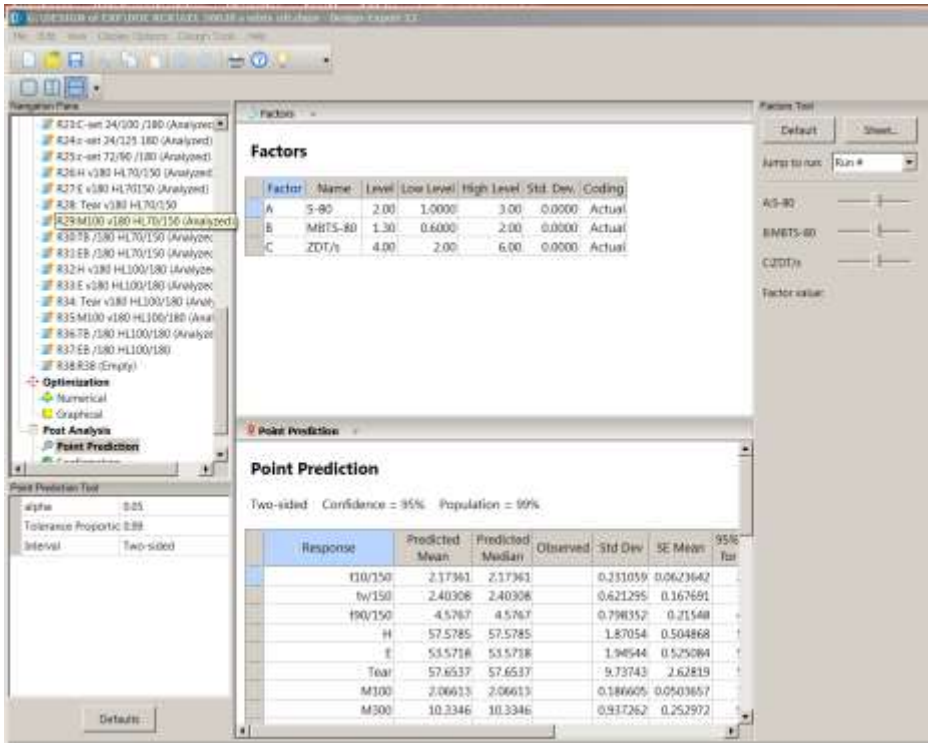
The Prediction is calculated with the

- **Intercepts and**
- **Regression Factors:**

(*Table shows case for linear regression*)

Response	Intercept	F1	F2	Fn
R1	A_1	$A_{F1.1}$	$A_{F2.1}$	$A_{Fn.1}$
R2	A_2	$A_{F1.2}$	$X_{F2.2}$	$A_{Fn.2}$
.....	.....	.....	.....	.....
Rn	A_n	$A_{F.n}$	$A_{Fn.n}$	$A_{Fn.n}$



Point Prediction Tool in Design Expert®12 Software (Screen shot)

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Algorithm used in AI Programming

- **k-Means-Algorithm**
  - **Creates cluster, calculates mean (Centroid) reorganization, Iteration**

- **Genetic Algorithm**
  - **Proposed Solution, iteration and mutation towards optimum, selection of results with “fitness” function**

- **Neuronal Net**
  - **Complex algorithm (Neuron): Calculation of a weighted sum, normalization to emphasize or dampen the summands. „Input – Hidden – Output“ layer. Feed Forward Networks / Recurrent Neuronal Networks**

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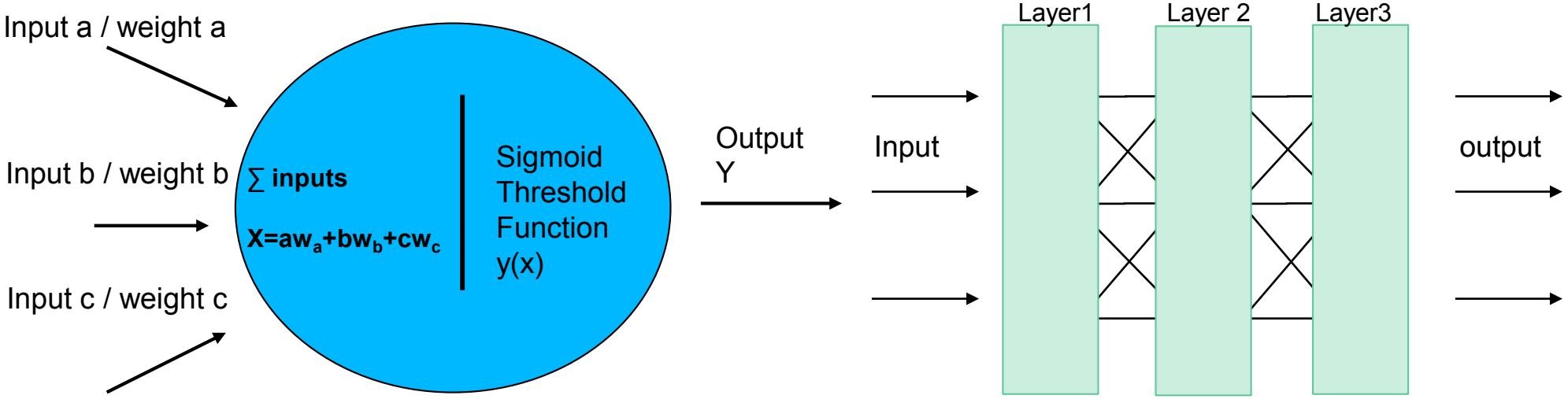
Source: T. Rashid, Neuronal Nets, 2017

Artificial Intelligence: Neuronal Network and Algorithm



Extended model of an artificial neuron with moderated input weights

A model with multiple layers of neurons, each connected to the preceding and succeeding layer.

- Weights could be assigned to the connections between nodes

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Source: T. Rashid, Neuronal Nets, 2017

Matrix multiplication with the terminology of neuronal nets

*(**w** – weight, **I** = Input, **O** – X-Matrix multiplied sigmoid function)*

$$\begin{bmatrix} I\ 1 \\ I\ 2 \end{bmatrix} \quad \begin{bmatrix} w\ 1{,}2 & w\ 2{,}1 \\ w\ 1{,}2 & w\ 2{,}2 \end{bmatrix} = \begin{bmatrix} I\ 1 * w\ 1{,}1 & I\ 2 * w\ 2{,}1 \\ I\ 2 * w\ 1{,}2 & I\ 2 * w\ 2{,}2 \end{bmatrix}$$

The input values for the subsequent layer is in each case:
X = w * I

Each x must be treated with the sigmoid, respective activation function:

$Y = 1/(1+e^{-x})$

Values for subsequent layers change to:
O = sigmoid (**X**)

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Source: T. Rashid, Neuronal Nets, 2017

Basic Idea of Neuronal Network Calculation:

- The calculation of signals passing through a neural network can be modeled as a **matrix calculation**.
- The links can be specified more precisely independent of the size of the network.
- Programming languages designed for matrix calculations can perform such calculations efficiently and quickly.

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Ingredients

Properties

Rubber Recipe Data Stag

- **Ingredients**
  - **Normalized to 100 parts polymer = phr**
- Properties
  - Rheological properties
  - Physicals
  - Other
    - Appearance
    - Dynamics

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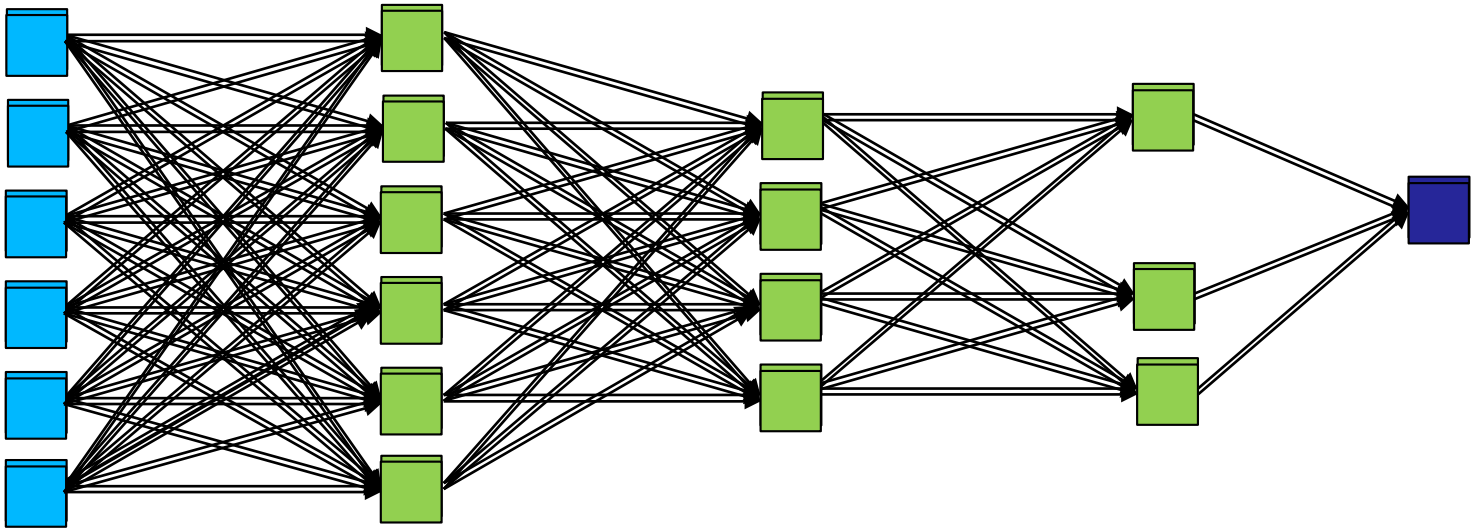
A square represents one dataset = data stag consist of n data



Input **1. Layer** **n. Layer** **n + 1 Layer** **Output**

Each square represents recipe and property information

- **Solutions closer to targets survive**
  - **Walking gradient method**

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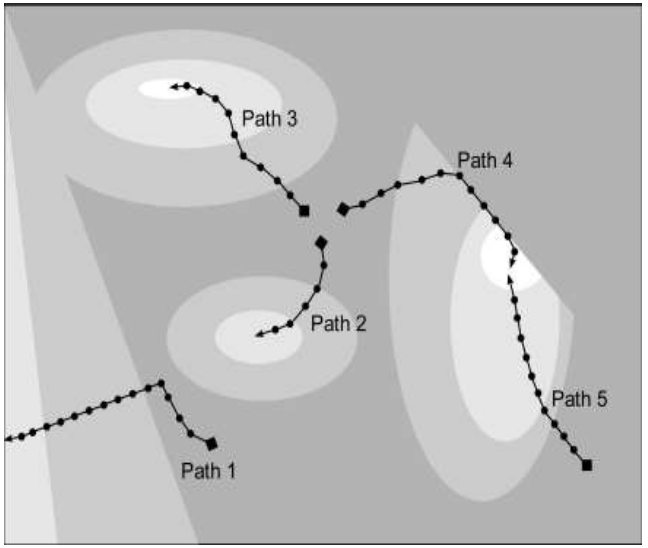
- **Database (historic, probably incomplete)**
- **Input: Data + Multi target query**
  - **Search for the best compromise with K-Mean / Multi Objective Evolutionary Algorithm (MOEA)**
  - **Numerical Solution with a Gradient Walking Method. Data treatment simultaneously.**
  - **Approximation / Desirability Function calculates distance from target.**
- **Output:**

  Recipe with Ingredients and its Properties



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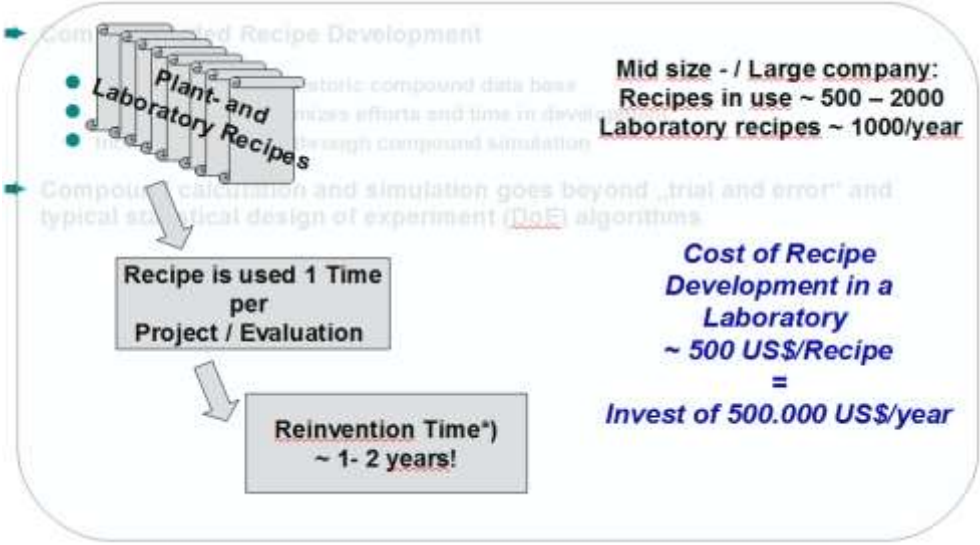
Compound Database Characterization

- Unorganized
- Incomplete
- Inhomogeneous



Solution of Database Quality

Inclusion / Exclusion of recipes from query.

Analytical tools for transparency:

Backtracking to data set used for Result *(Opposite to AI Programing)*

Combination of data sets with merger function

Confirmation Experiment of Results

Verification prior to integration in database

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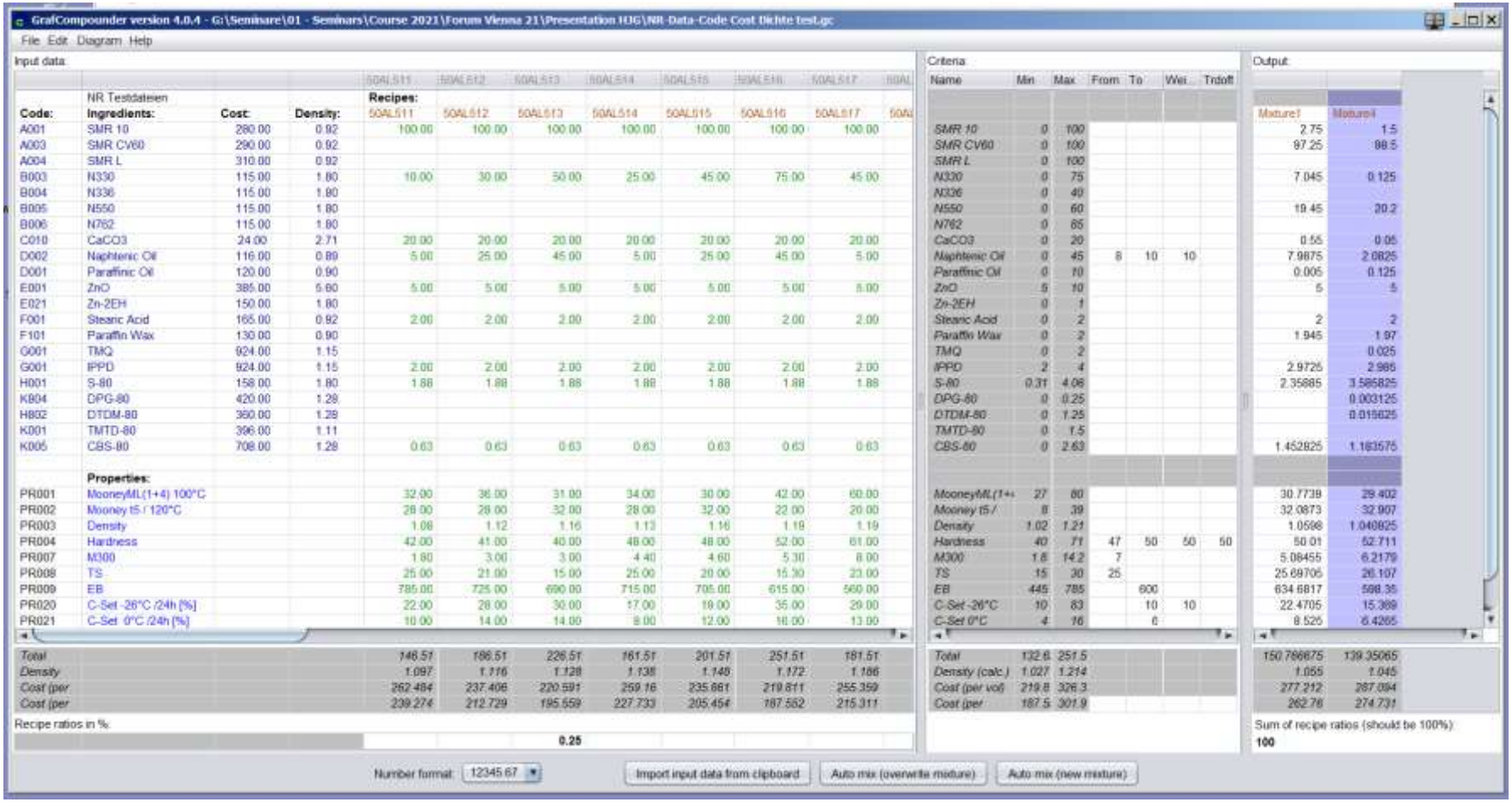
➔ Screenshot of GrafCompounder with demo data, targets and a calculated compound



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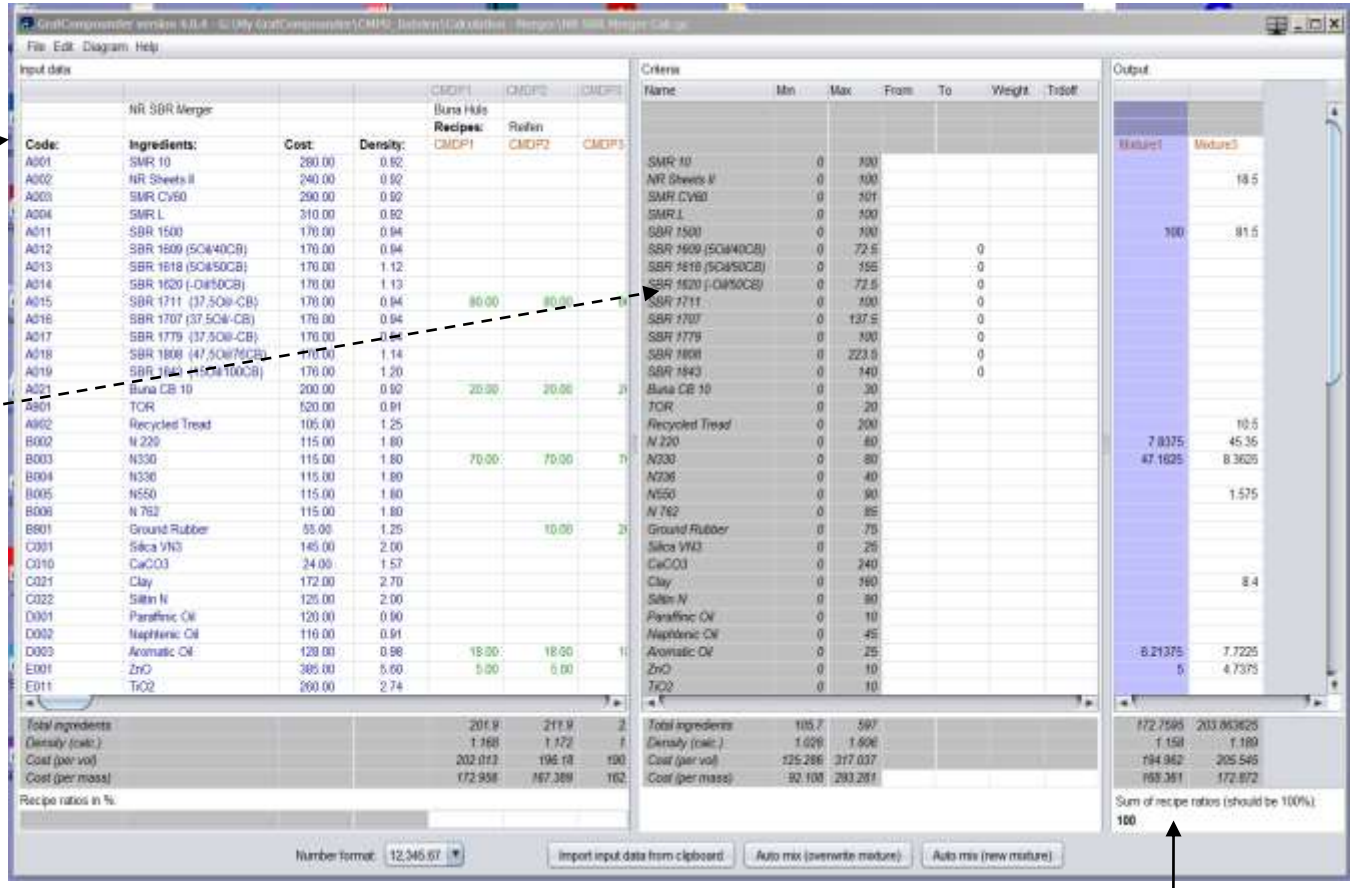
GrafCompounder Screen

- **Data field**
  - Code
  - Ingredient name
  - Cost information
  - Density
- **Criteria field**
  - Min/Max Value
  - Query column:
    - From
    - To
    - Weight
    - TrdOff
- **Output field**



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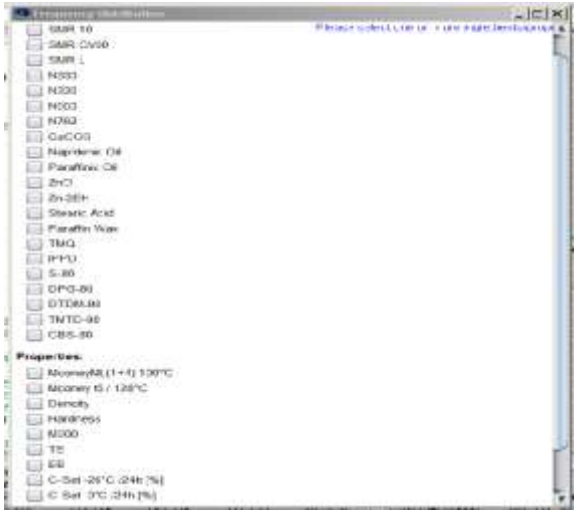
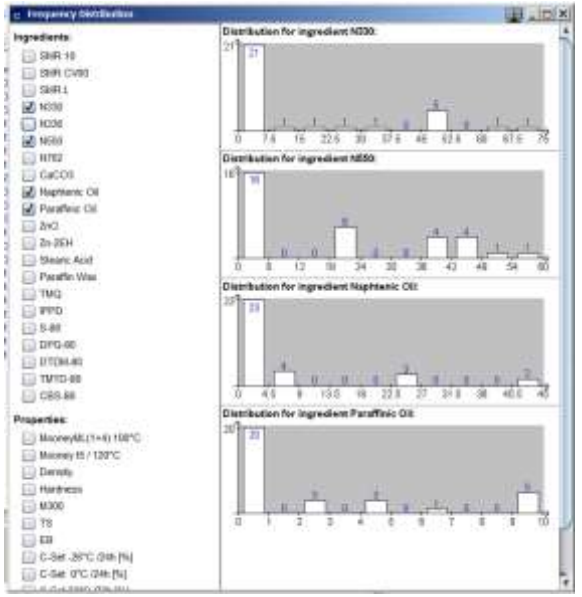
Database Diagnose Tool

- Frequency distribution of
  - Ingredient
  - Property

  can be chosen

- Scale is automatically selected according
  Minimum and Maximum value in the database





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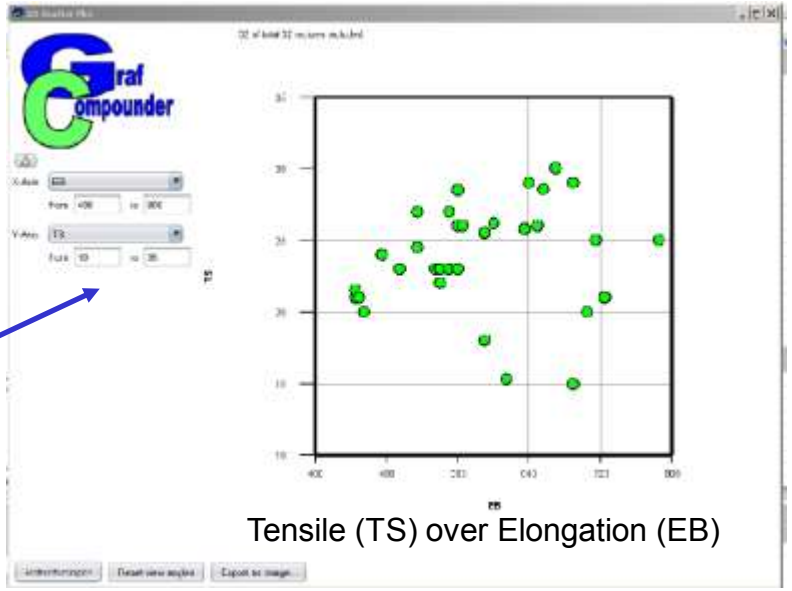
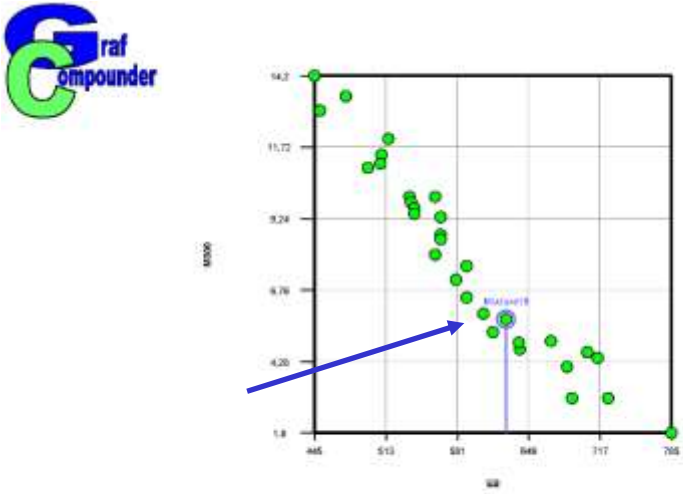
Database Diagnose Tool

- **Correlation Diagram**

- **Example:**
  Tensile (TS) over Elongation at Break (EB)
  - **Scale for axis**
    Selected
    - automatically / - manually
  - **Highlight recipe for evaluation or exclusion**



Tensile (TS) over Elongation (EB)



Modulus M300 over Elongation (EB)

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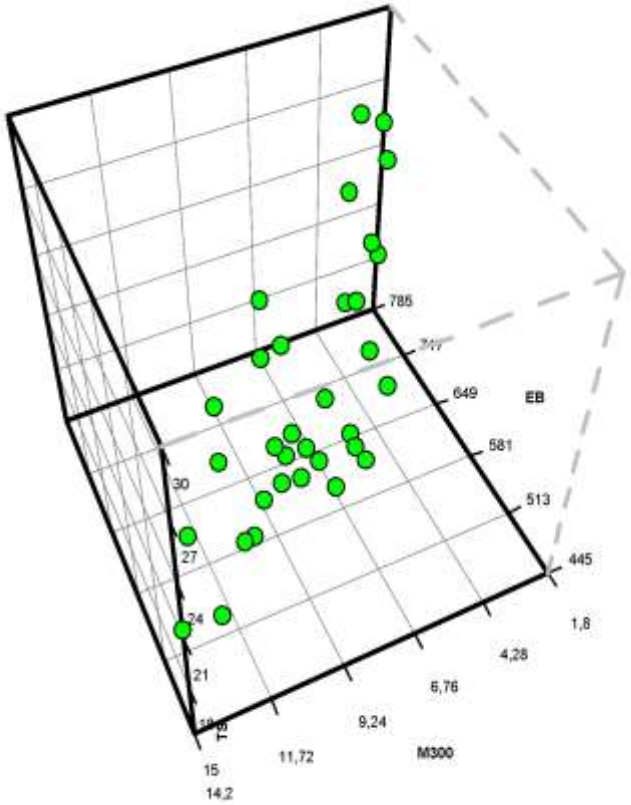
Database Diagnose Tool

- **3D Correlation Diagram**

- **Example:**
  - **X- axis: Elongation at Break (EB)**
  - **Y- axis: Modulus 300 (M300)**
  - **Z-axis: Tensile at break (TS)**

- **Scale for axis:**
  Selected automatically / manually



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How to do a query:

1. **Ingredients**
   Exclude with target = 0
2. **Properties**
   - ✓ **Target from Min value to Max value**
   - ✓ **Put a weight on property target,**
     if more important than others
   - ✓ **In case of conflicting target:**
     Give a preference with Trdoff:
     Back off a bit from the target in favour
     of others

	From	To	Weight	Trdoff	Mixture1	Mixture2
2						0.025
4					2.9725	2.985
4.06					2.35885	3.585825
0.25						0.003125
1.25						0.015625
1.5						
2.63					1.452825	1.183575
80					30.7739	29.402
39					32.0873	32.907
1.21					1.0598	1.040925
71	47	50	50	50	50.01	52.711
14.2	7				5.08455	6.2179
30	25				25.69705	26.107
785		600			634.6817	598.35
83		10	10		22.4705	15.369
16		6			8.525	6.4265
18		10			7.9618	4.838
61		15	10		26.3231	22.0725
51.51					150.766675	139.35065
1.214					1.055	1.045
26.37					277.212	287.094
01.915					262.76	274.731

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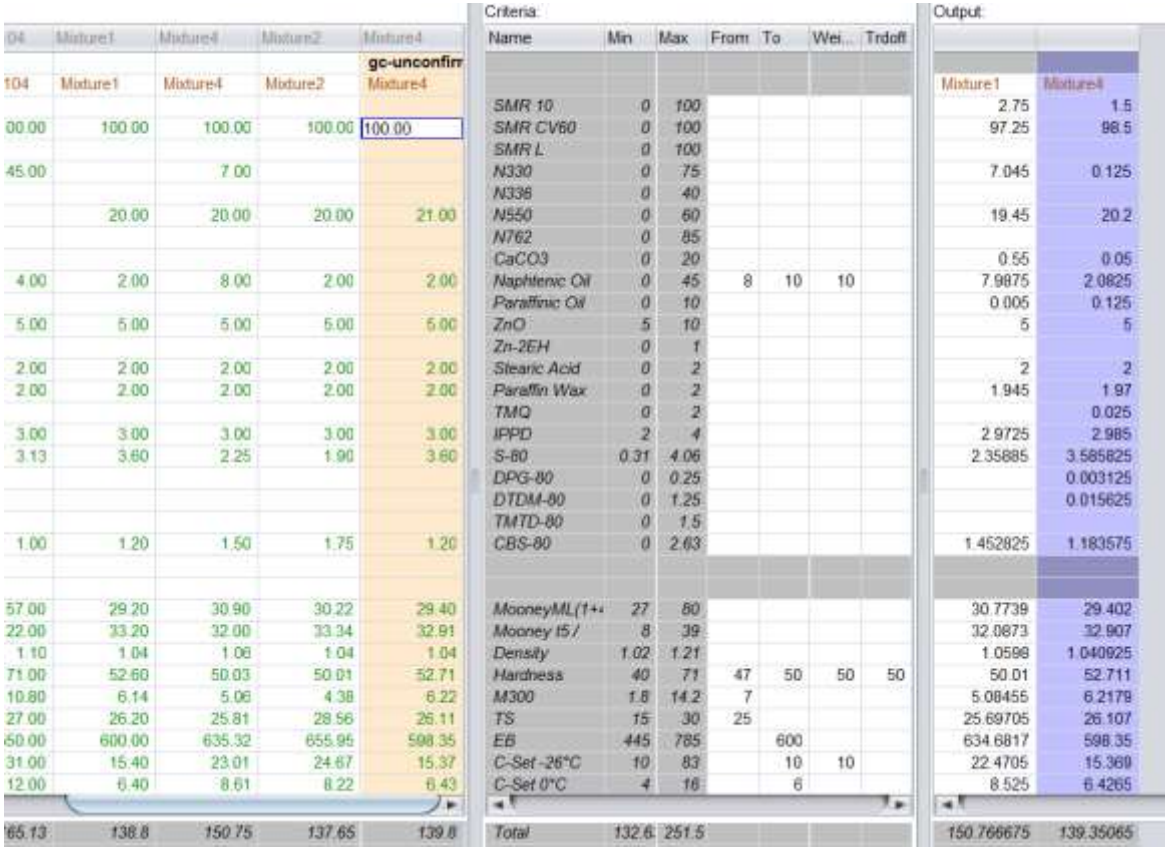
- **Recipe for confirmation experiment**
  - **Append selected recipe in "Input data" field**
    - **It is highlighted as "gc-unconfirmed"**
- **Interaction with user**
  - **Eliminate nonsense values and consolidate**
  - **Round values to two decimal places**
- **Confirmation**
  - **Experiment: Change property values to confirmed values**



Compound Simulation with GrafCompounder

- Creation of a formula with multiple criteria query including
  - Ingredients
  - Properties
- Traceability back to each formula used in calculation
  - Analysis of outliers and their correction or elimination in the database is possible.
  - Integration of results from statistical experimental designs to improve database
  - Merger of databases of different origin
    - either with copy / import from table calculation program
    - Merger of data.gc files

Result of simulation MUST be confirmed by an experiment.

- Probability of a match between calculation and confirmation experiment result is about 90-5% according first experience

Experiments to evaluate accuracy of the method

- To prove calculation of recipe using a database or even historic data from literature three experiments were chosen:

1. Recalculation of Filler / Oil DoE (EPDM Extrusion Compound)

2. EPDM ENB / Accelerator DoE recalculation (published by DuPont 1998) for optimum ENB content and None n-nitrosamine accelerator system

3. Prediction and Confirmation Experiment
   Existing development project

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Calculation method confirmation

- Prove with
  1. EPDM Filler / Oil DoE – most of basic physicals are linear
  2. Filler / Oil DoE
  3. Accelerator DoE

1.

DoE with 4 Factors

Polymer used: EPDM (Vistalon 8600)

Factor	Name	Units	Min	Max
A	C6630	phr	60.00	95.00
B	CaCO3	phr	10.00	70.00
C	Clay	phr	10.00	50.00
D	Oil	phr	70.00	95.00

- A fractional factorial DoE with 11 compounds only!

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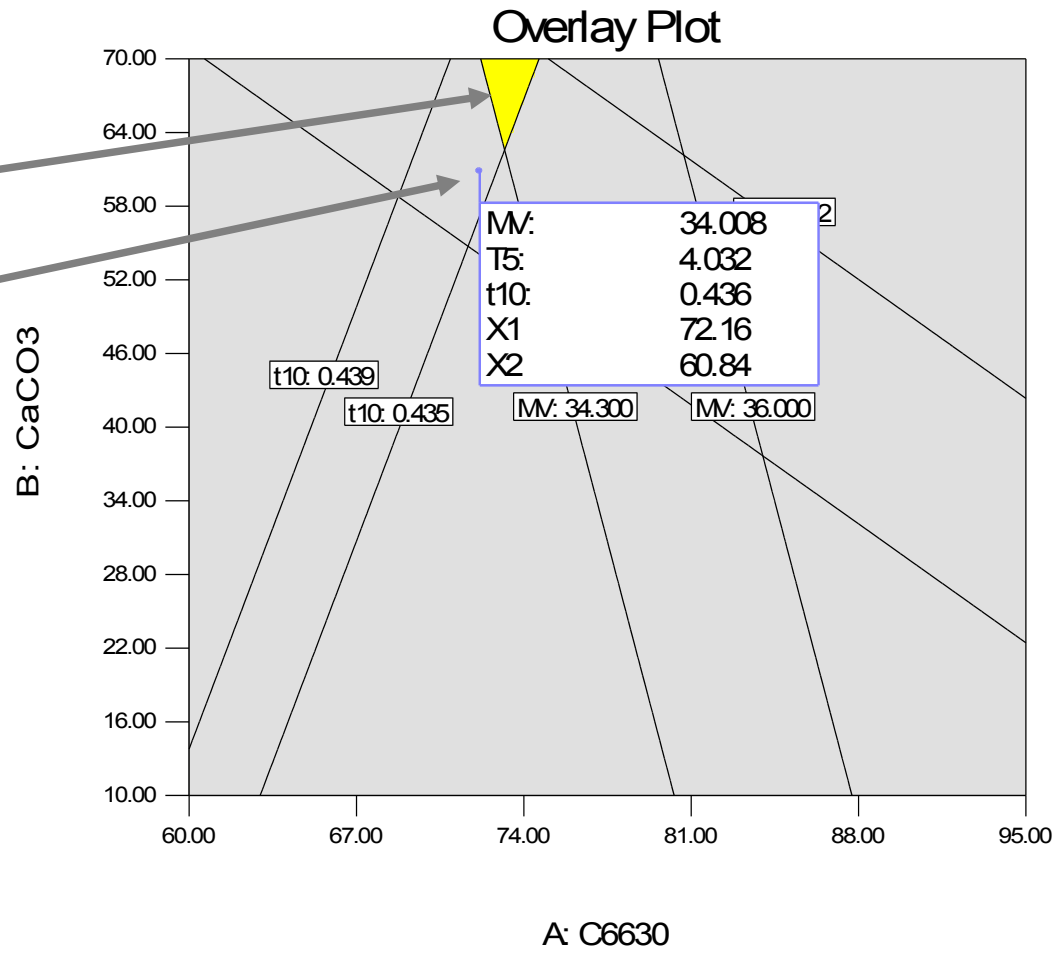
Optimization area calculated with Design Expert

Solution given by GrafCompounder

with the additional condition (CC 6630 – 73 phr)



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2.

DoE published by DuPont Dow in 1998

- **Factors: ENB, DTDC, S, MBT, TiTBD, ZdiBC, DTP**
- **DoE with 41 Experiments**

Tensile at break is significant with linear model

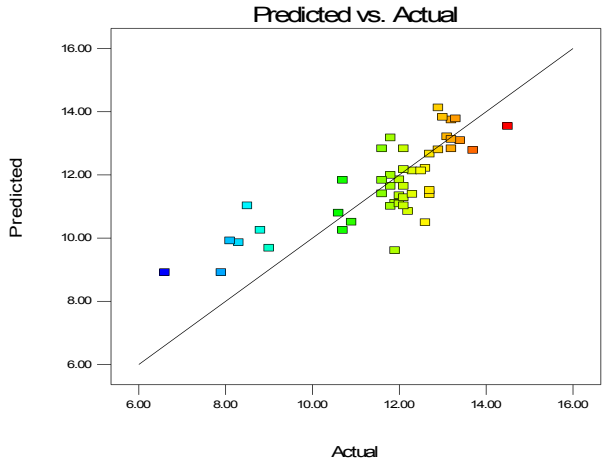
- **Sulfur has larger influence followed by DTDC and TiBTD, but negative**

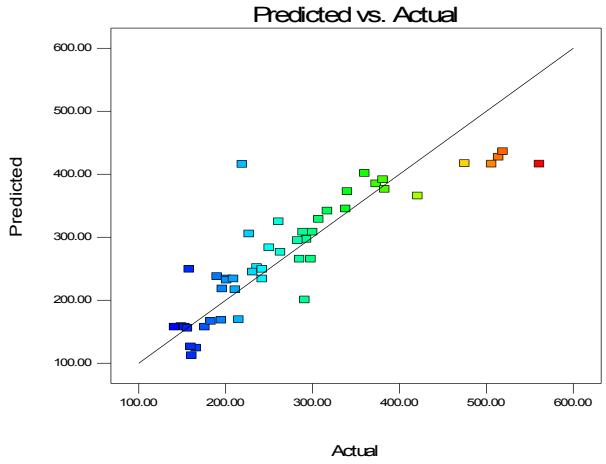
Elongation is significant with quadratic model, but linear model is a more than sufficient fit

- **Sulfur has the largest influence followed by DTDC**

Hardness is sufficient significant with linear model as well

- **Main influence Sulfur, DTDC**





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- **Boundary Conditions**
  - **Select boundaries**

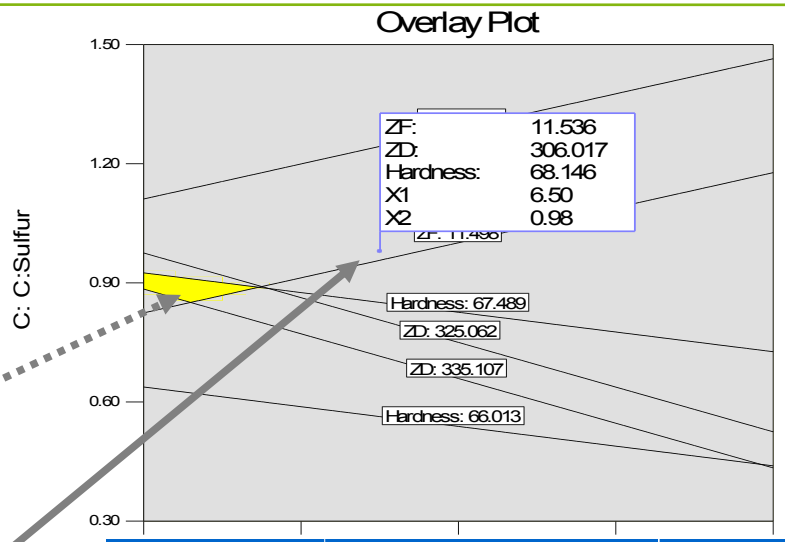
ZF-MPa : 11.5-12.0

ZD-% : 325-335

H-° ShA : 65-67

The Design Expert optimization graph shows the location of the result as a yellow area, but

GrafCompounder result is tagged with a flag.



Ingredients	GrafCompounder	Design Expert®
ENB	6.5	5.45
C:Sulfur	0.93	0.88
B:DTDC	0.98	0.98
D:MBT	1	1
E:TiBTD	1.51	1.51
F:ZDiBC	1.33	1.33
G:DTP	1.45	1.44
ZF	11.5	11.5
ZD	325	330
Hardness	67	67.5

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Graf Compounder

HJG

3.

Prediction and Repeat in an Experiment in Laboratory

	EPM Compound No1			EPM Compound No2		
	Predicted	Test results	Deviation	Predicted	Test results	Deviation
Hardness	69.99	70.00	0.01%	60.28	61.00	0.59%
Tensile at Break	19.56	18.75	2.16%	15.74	18.08	6.47%
Elongation at Break	338.61	339.00	0.06%	513.48	476.00	3.94%
M 100	3.87	4.75	9.26%	2.04	3.05	16.56%
C-Set 23°C / 22h	10.28	10.91	2.89%	10.00	9.97	0.15%

Data in good agreement except Modulus 100

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Statistic Experimental Design (DoE)

- Organized / Limited size Data set
  - *DoE's with large amount of Factors difficult to handle and analyze*
- Variation of few factors according DoE scheme
  - *Evaluation of a portion of compound*
- Measurement error statistically evaluated (ANOVA)
  - Experimentation controlled
    - Lack of fit test – noise to signal ratio
    - Significance (F-value, p-value, Fit statistics)
- Optimization, numerical and graphical / prediction Tool available in the software

Advantages of DoE

- Evaluation of New Raw Materials
  - Correction of Compound due to Raw Material Changes
- Process Optimization
  - Operating Window / Process in control according SPC
  - Process Design with new machines / raw materials

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Compounder

- Unorganized / Unlimited Database
  - Measurement error unknown
  - Incongruent values (due to different test methods)
  - Raw materials in Laboratory (Storage time?)
  - Missing values
- Multiple Factor Query
- Compound Simulation according Multi Targets

Calculation in multiple small steps excludes none linear effects.

Accurate Property Data yield Output in 95% confidence interval.

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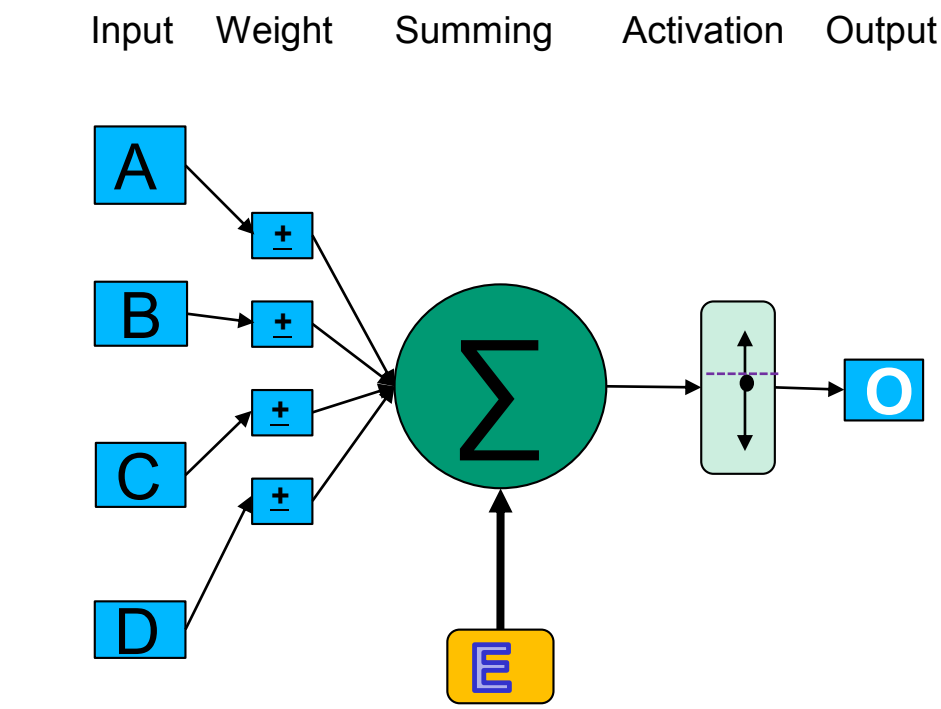
Source: S. Velasco in Spektrum 11/21

Challenges and Hints to machine learning with "Back Propagation" in rubber compounding:

- **Time consuming testing specifically long term aging / dynamic**
- **Compound preparation to generate data with high effort.**
  (Tests with laboratory generated data has failed in the past)
- **Database standardization**
  - **Basic data collective**
  - **Specific data collective**
- **Identification of data errors**
  - **Data transfer errors**
  - **Compound preparation / measurement errors**



Errors:
The nerve cell learns via errors to optimize the weighting and the values of the input function.

Conclusion:

- **Compounder Program**
  - Compound Cost estimation
  - Starting Formula for Compound Development
  - Simulation of Recipe for Specification Adjustments
  - Historic Data usage and improved Data storage
- **Statistic Experimental Design**
  - Evaluation of New Materials
  - Cost optimization in Compounding
  - Design / Improvement of New Processes
  - Process Window to Control Quality according SPC
- Combination of Database / Compound Simulation with Statistic Experimental Design Experimentation Procedure

Both methods have their justification.

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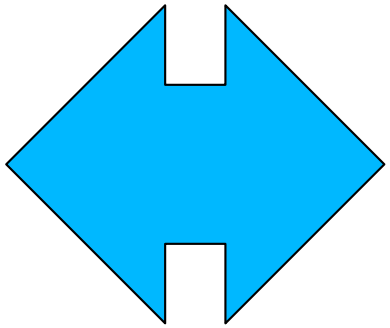
GRAFCOMPOUNDER

- History
- Analyze
- Simulate
- Select
- Confirm



EXPERIMENTAL DESIGN

- Explore
- Evaluate
- Decide
- Confirm
- Conclude

➔ **Release of the „GrafCompounder“ Version 4.0 was June 2021**

➔ **Upgrades for Owners of Version 3.211 provided for a special price**
Free upgrade if purchased 2nd half 2020 / 1st half 2021

Thank you for joining this presentation.

➔ Questions, Remarks, Discussion ?

More information under: **www.grafcompounder.com**