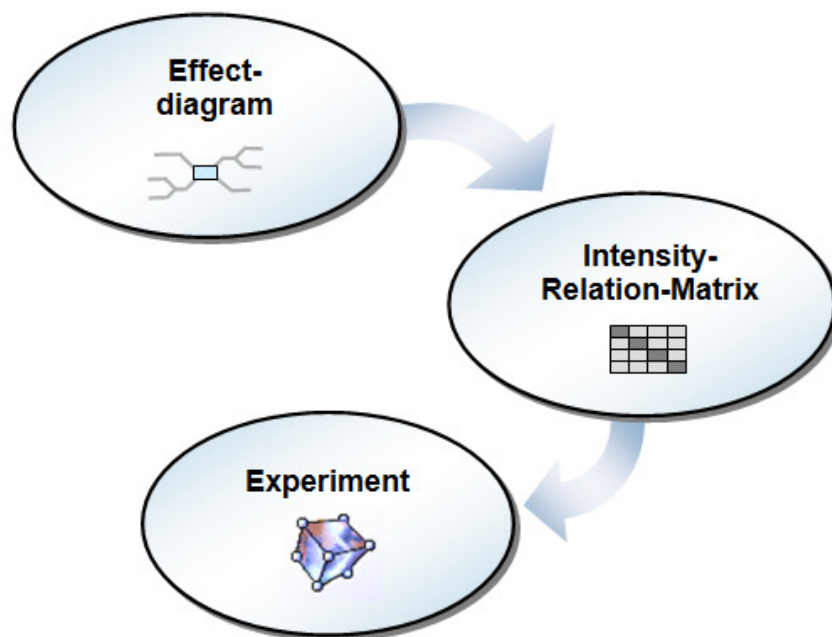# System Analysis
From the
Cause-Effect-Diagram
to a DoE

1st Part

Basis instructions

System analysis

The solution of technical problems becomes more and more difficult on account of complicated growing systems. In this connection Design of Experiment (DoE) is often used meanwhile also in connection with SixSigma. However, unfortunately, test planning fail because of the insufficient preparation. The best statistical methods cannot value left out and underestimated factors from the observation. With the help of an example should be shown, how the best possible systems analysis as an entrance for Design of Experiment.

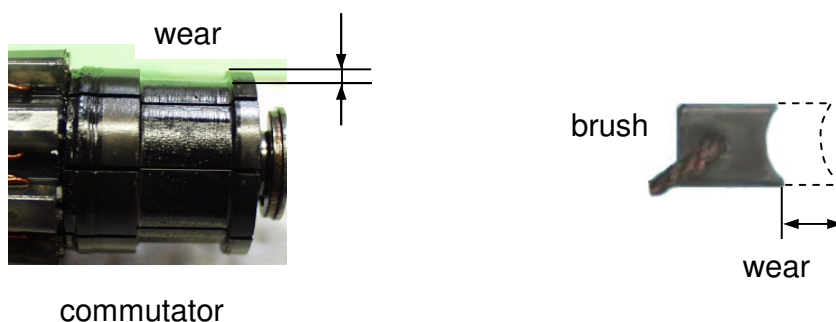A systems analysis is a systematic investigation of elements which are in relation together.

One understands by the concept Systems Analysis a huge number of methods and representations. Within the scope of these descriptions the methods which are important for a later investigation, in particular creating test plans, should be limited.

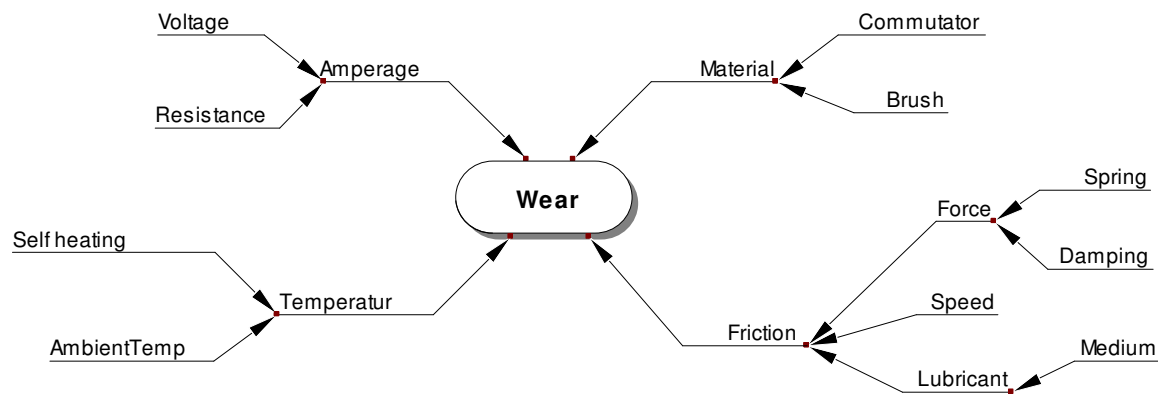The most important tool is the Cause-Effect-Diagram

Cause-Effect-Diagram

The block diagram is mostly a representation purely oriented to the components. This action is suited for the basic understanding of the constructive background of the system. Connections of the functions and effects are returned with it, however, only insufficiently or not at all.

A substantially better possibility for solving problems is to put the error pattern in the foreground. The procedural method should be described on the following example. In the development of a new engine there was a wear problem in commutator and brushes.

commutator

brush

wear

wear

If one uses here instead of the components physical / technical issues for the causes of wear, there can be shown the following possible simplified representation:
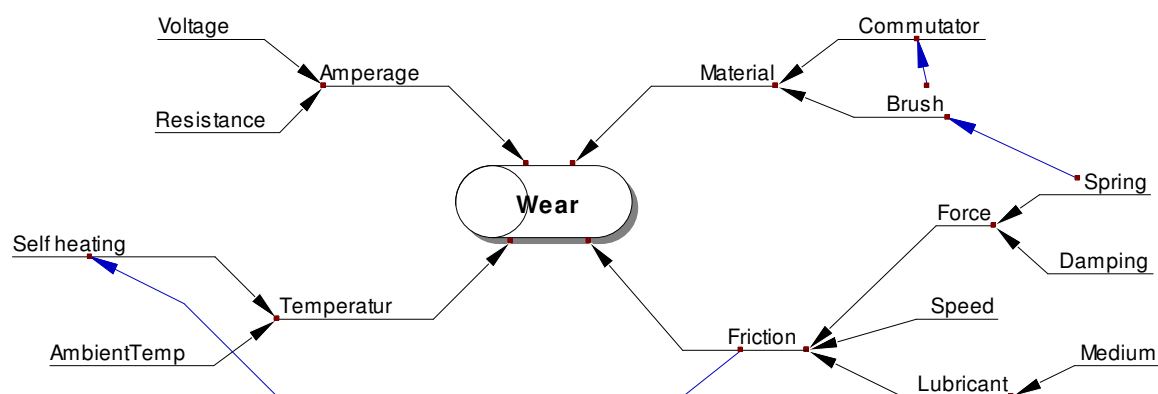
The shown subdivision has the advantage that the cause effect order is clearly recognizable and takes into consideration a later assessment of the causes the wear better.

Consideration of interconnections (relation diagram)
By closer consideration physically there are relations between some points. The resistance depends on the temperature and the self heating on the friction. These will be described through the additional interconnections:

The next step is the assessment of the Cause-Effect-Diagram with the help of the so called Intensity-Relation-Matrix.

The Intensity-Relation-Matrix
The intensity relation matrix shows a kind of network analysis and comes from the method of the linked thinking for solving complex problems. This method was developed and introduced by Frederic Vester and was also called "paper computer". With this easy method effect intensities between factors in a complex system can be estimated.

Regarding test plans and further investigations there can be found out the important factors (parameters). The task is also to reduce the amount of factors which are not relevant.

The quadratic matrix is so constructed that the factor names stand in the first column an in the same sequence also in the first row. Then there is to evaluate (estimation) the cause-effect from the factor in the column to the factor in the top row. The matrix structure (cell by cell) ensures that all pairs are evaluated.

The degree of the effects is estimated as a rule by experts or experts:

    0 = no effect
    1 = low effect
    2 = middle effect
    3 = high effect
    5 = very high

Some times it is necessary to use a 5-level value for top effects of main factors.

Nevertheless, the input of 0 has the advantage that one point out which cells where worked on. After an interruption of the assessment later on this is a marker where to continue. The following possible matrix arises from the preceding representation oriented to the problem of the electric motor under inclusion of the interconnections:

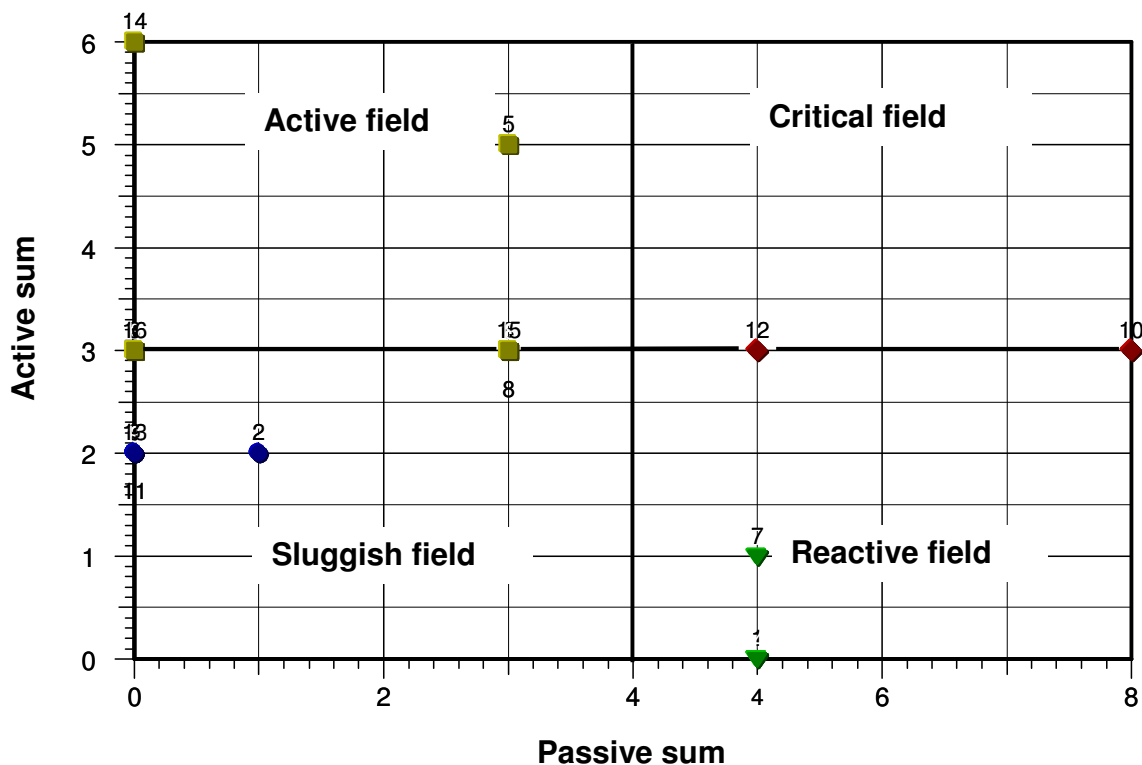| Effect from to ->	1 Amperage	2 Resistance	3 Voltage	4 Material	5 Brush	6 Commutator	7 Temperatur	8 Self heating	9 AmbientTemp	10 Friction	11 Speed	12 Force	13 Damping	14 Spring	15 Lubricant	16 Medium
1 **Amperage**	■															
2 Resistance	2	■														
3 Voltage	3		■													
4 **Material**				■												
5 Brush				2	■	1										
6 Commutator				3		■										
7 **Temperatur**		1					■									
8 Self heating							3	■								
9 AmbientTemp							2		■							
10 **Friction**								1		■						
11 Speed											■	2				
12 **Force**											3	■				
13 Damping													■	2		
14 Spring				1									3	■		
15 **Lubricant**											3				■	
16 Medium															3	■

New in the variation shown here is, compared with the literature, the inclusion of the preceding effect graphic consideration.
White marked cells mean that direct effect (arrows) exist in the cause-effect-diagram. Light grey fields are interconnections (cross arrows). Those fields must be evaluated in each case. The dark gray fields are to be checked again whether here effects were overlooked. May be some interconnections were forgotten.

After the assessment there will be calculated row by row all active sums (horizontally). The sums of the columns represent the passive sums.
Each point (factor) will be applied about passive and active sum in a dot-plot-diagram. The origin of the axis is at 0. The x-axis end is the maximum passive sum. The y-axis end is the maximum active sum. Then the diagram is split horizontally and vertically in

equally halves. This creates four fields, which are important for the further evaluation. These represent the so called active-, passive-, critical- and the sluggish field. For further investigations the factors in the active- and the critical-field have to be considered. Interactions are expected between the factors in the critical field among each other and between the factors in the active-field. The factors in the sluggish field can be renounced. The factors in the reactive field can be considered as uncontrolled factors which are not varied in the test plan. Because of the passive behaviour those factors are often further responses (measurements).

The independent factors in the active- and critical-field are

Voltage, brush, commutator, self heating, spring and **medium**.

Although the title self heating is in the border area, this is depending on the friction. The variation is difficult. Therefore the variation will be controlled through the ambient temperature of the test rig. The title is simplified to temperature.

The number of independent factors could be reduced from 10 to 6 an now we have:

6*(6-1)/2=15 interactions.

These are:

voltage*brush				
voltage*commutator	brush*commutator			
voltage*temperatur	brush*temperatur	commutator*temper.		
voltage*spring	brush*spring	commutator*spring	temperatur*spring	
voltage*medium	brush*medium	commutator*medium	temperatur*medium	spring*medium

Voltage*srping, commutator*temperatur (self heating) und spring*medium make no sense and will be taken off.

The minimum number of tests for D-Optimal design from this action is:

$$n = 6 + 15 - 3 + 1 + 1^* = \mathbf{20}$$

The minimum number of tests for D-Optimal design taking into account all independent factors would be:

$$n = 10 + 10*(10-1)/2 + 1 + 1^* = \mathbf{57}$$

* Note: +1 for determining the constant and additional +1 for „degrees of freedom" to evaluate scatter

Out of this a saving of 37 attempts arises

The essential point with this example is that the assessment has not occurred only between the independent factors (factors in the border area of the cause-effect-diagram). Rather the dependent dimensions amperage, temperature, friction and material were also incorporated. An assessment focused on the problem is possible only through this!

If the possibility exists to vary the settings of the dependent dimensions by spare check (lab test or simulation), other interaction can be reduced as a rule and the test plan becomes even easier.

Important aspects

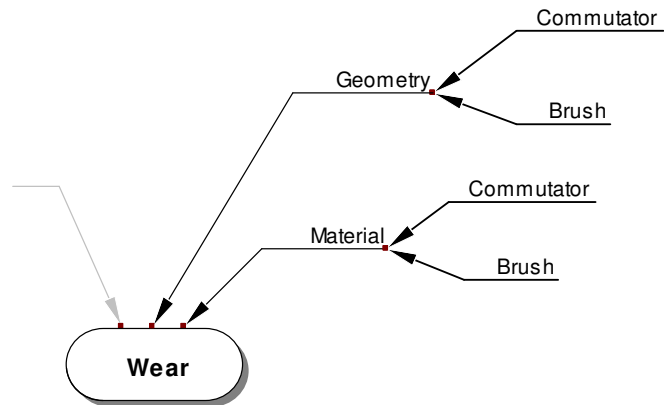### Disproportionate very active factors

Sometimes it can be that a factor shows an active sum very high by far and perhaps passive sum towards other. The axis area is determined by this factor and all the other factors appear almost only in the passive field. Then the described division in four fields and their interpretation does not make sense thus any more. Remedy is a temporary repetition without this title.

Not varied parameters and consideration of the response

Physically the wear increases over the time. However, the time was not taken into consideration in the Cause-Effect-Diagram. This can mean that only a relative wear per time unity is meant as a title, or that a test is always driven with the same time. The parameter time is regarded therefore as steady.

Subdivision in geometry and material

Furthermore no geometrical qualities were used in the diagram. In the problem solution process dimensions and constructive attributes are not mostly changeable. However, in the development phase these are absolutely to be taken into account. In the subdivision between geometry and material the same components can be seen several times. Besides, direct physical dependence is not to be forgotten, for example the dimension changes for elastic materials and force. Nevertheless productivity dependencies are not to be regarded as physically effects. For example if there are not enough package space and therefore it has to be used a higher material quality, this effect is not to considered here.

Cause effects versus Interactions

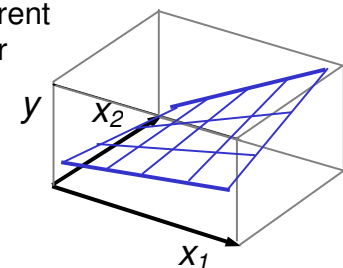With the representation of graphic connections the differences are to be followed between effects and interaction!

Cause effects (evaluation in the Intensity-Relation-Matrix)
Factors work on other factors and influence this. Out of this arise with not controlled processes correlating data. In a controlled process correlations can be avoided and a test plan be generated. Example: Friction generates self heating. This can be prevented by external cooling.

Interactions

An interaction is the different change of the response by concurrent change of another factor. The direct effect of a factor on another does not mean automatically that an interaction covered to a response exists. Interaction has a physical cause.
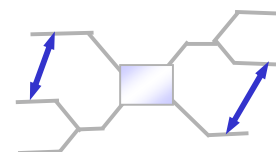Interaction is accepted in particular in the Intensity-Relation-Matrix in the critical field.

Interconnections in the cause-effect diagram

if this represent cause-effects:
   ☞ Further analyses via Intensity-Relation-Matrix

if this is defined as interactions:
   ☞ Direct definition for test-plan
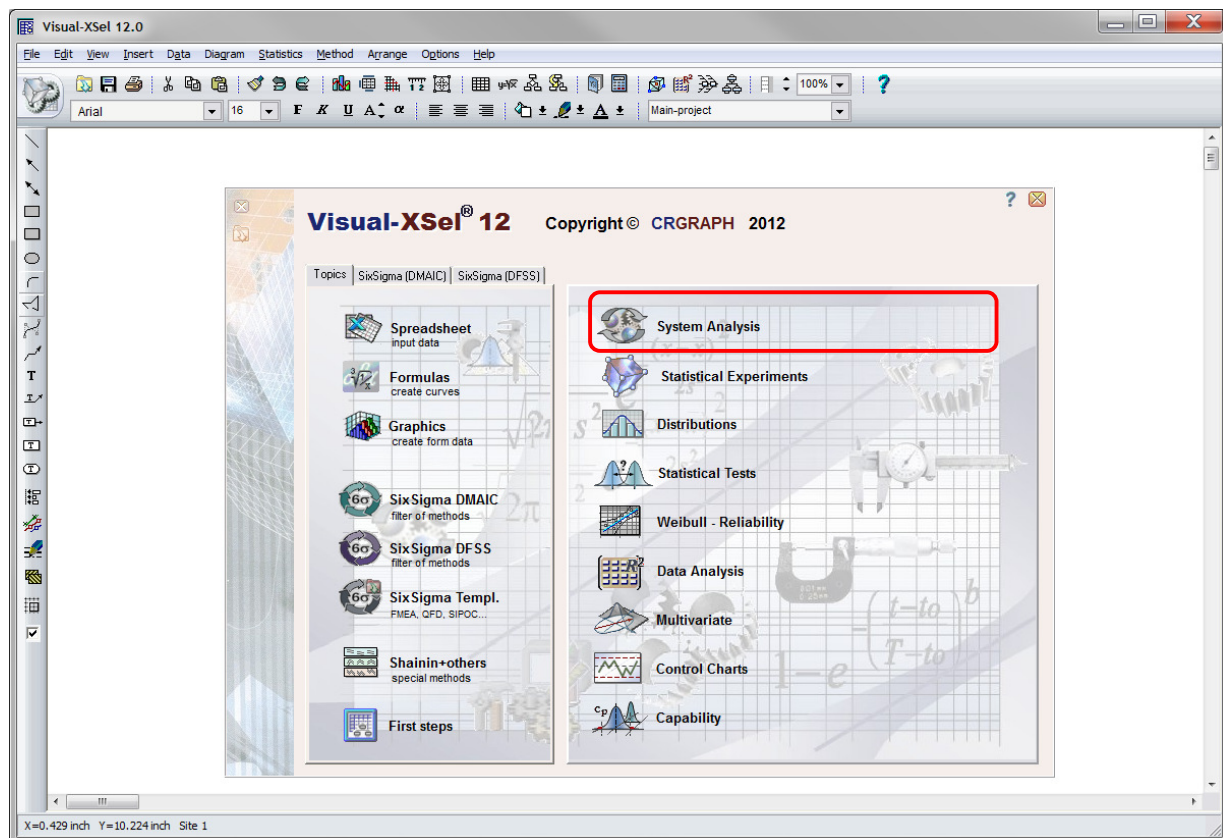
Summary action plan

To summarise one can define the following 7 steps of the systems analysis up to the test plan

1 Identification of the physical dimensions and factors by brainstorming.

2 Graphical description as structure- and cause-effect-diagram Consideration of the interconnections

3 Create Intensity-Relation-Matrix from diagram and evaluate

4 Create the Intensity-Relation-Diagram

5 Select the factors in the active- and critical-field and use interactions form this

6 Possible reduction of the interaction from the full amount of combinations because of not possibly technically / physically connections

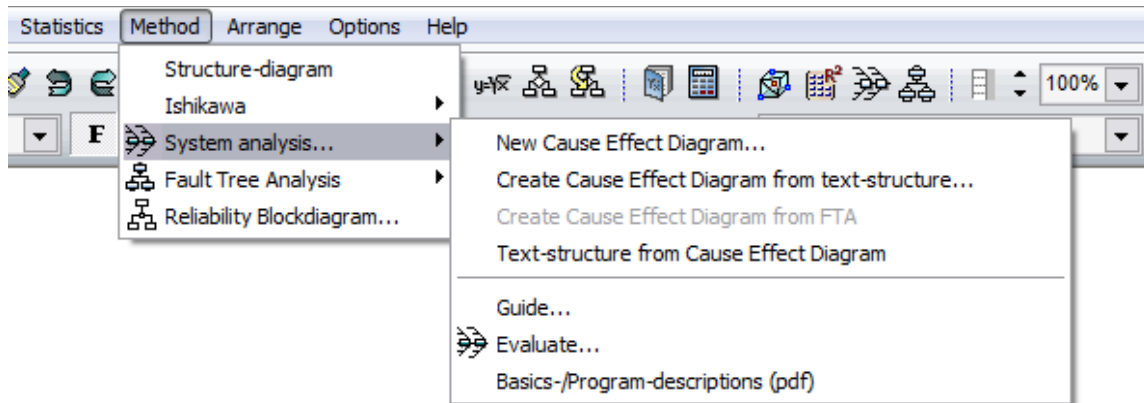**7** Create D-Optimal test plan

Often the first and second step is combined. But the recommendation is to make a brainstorming first. Otherwise the creative process is steered too much in a certain direction.
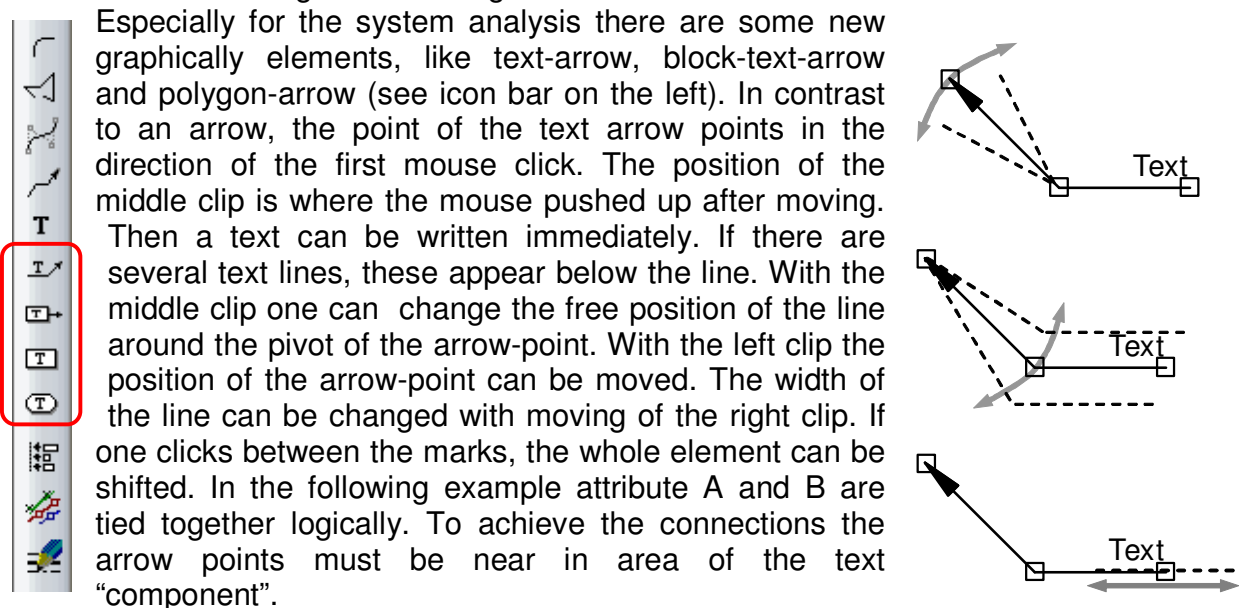
2nd Part

Program instructions
Visual-XSel 12.0

In version Visual-XSel 12.0 Multivar structural diagrams, as well as systems analyses can be carried out.

The entrance in the systems analysis is about the menu point Method/System analysis/New (Guide). At first a structual, or better a cause effect diagram is to build up graphically. The subject to be treated, or the title stands as a main block in the middle or with the Ishikawa diagram on the right. Around this title the effects have to be defined.

Especially for the system analysis there are some new graphically elements, like text-arrow, block-text-arrow and polygon-arrow (see icon bar on the left). In contrast to an arrow, the point of the text arrow points in the direction of the first mouse click. The position of the middle clip is where the mouse pushed up after moving. Then a text can be written immediately. If there are several text lines, these appear below the line. With the middle clip one can change the free position of the line around the pivot of the arrow-point. With the left clip the position of the arrow-point can be moved. The width of the line can be changed with moving of the right clip. If one clicks between the marks, the whole element can be shifted. In the following example attribute A and B are tied together logically. To achieve the connections the arrow points must be near in area of the text "component".

If one shifts now the element component, the elements stick to this firmly and are shifted with. If one shifts, however, the attributes A or B, in reverse direction the component is not moved with. If one wants to shift the element component only, the **Alt-key** is to be pressed at the same time. To insert a new element below, press **Ctrl-key** at the same time.

From these graphic representations a structure or an Intensity-Relation-Matrix can be generated (see menu Method/ System analysis or the marked icon in the top). There appears a dialog with the choice what should be already taken over for the
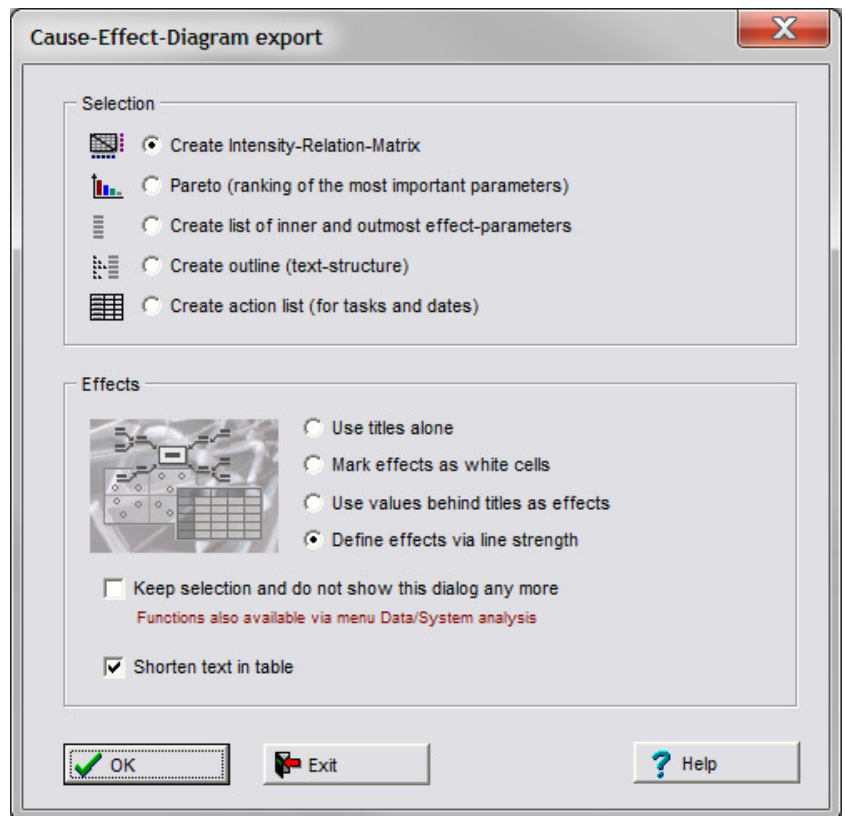
assessment of the Intensity-Relation-Matrix.

If chosen "Mark effects as white cells", in the Intensity-Relation-Matrix there must be assessed only those cells. The better way is to assess the effects already in the graphic.

This can be achieved either about numerical data behind the titles, or about the definition through the line strength (see the other descriptions also moreover on the following side).

Back to our example. The following sheet will be created after using option „Define effects via line strength":

At the places at which arrows point at other "titles" a white field is generated here and an assessment is necessary. But
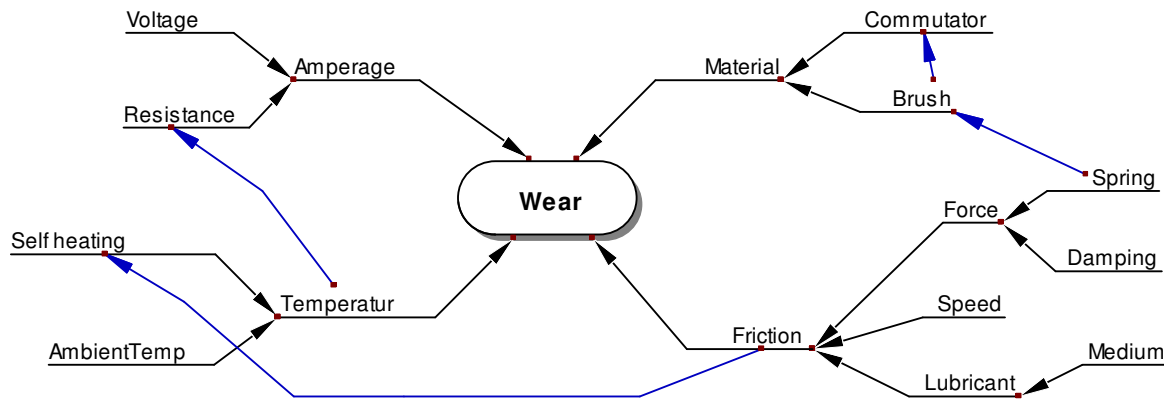
Cause-Effect-Diagram export

Selection
- ● Create Intensity-Relation-Matrix
- ○ Pareto (ranking of the most important parameters)
- ○ Create list of inner and outmost effect-parameters
- ○ Create outline (text-structure)
- ○ Create action list (for tasks and dates)

Effects
- ○ Use titles alone
- ○ Mark effects as white cells
- ○ Use values behind titles as effects
- ● Define effects via line strength

☐ Keep selection and do not show this dialog any more

Functions also available via menu Data/System analysis

☑ Shorten text in table

✓ OK   🚩 Exit   ? Help

Effect from to ->	Amperage 1	Resistance 2	Voltage 3	Material 4	Brush 5	Commutator 6	Temperatur 7	Self heating 8	AmbientTemp 9	Friction 10	Speed 11	Force 12	Damping 13	Spring 14	Lubricant 15	Medium 16
1 **Amperage**	■															
2 Resistance	2	■														
3 Voltage	3		■													
4 **Material**				■												
5 Brush				2	■	3										
6 Commutator				3		■										
7 **Temperatur**		1					■									
8 Self heating							3	■								
9 AmbientTemp							2		■							
10 **Friction**								3		■						
11 Speed										1	■					
12 Force										1		■				
13 Damping												1	■			
14 Spring				1								1		■		
15 Lubricant										1					■	
16 Medium															1	■

also connections of elements on others by arrows or polygon arrows generate marked fields.

The matrix can be regarded also as a check list, so that every parameter with each other was brought in relation.

If after the assessment in the table once more changes are necessary in the structural diagram, the values are deleted by renewed generating of the Intensity-Relation-Matrix in the table!

Therefore, it is better to define the effect-wheight via the line strength. See example:
*..\Templates\1_Systemanalysis\Effect_diagram_problem_oriented_wear.vx*g.

Click to one of the branches and use the right mouse button. Then these values are automatically taken over in the table. This information of effect values can be made visible via the menu "Show weighting as values".

There is the choice of weightings 1, 2, 3 and as an effect especially to be emphasised the strength 5 (line strength 1.0). The weight 9 is normally not to be used.

After the entire assessment in the sheet the evaluation can be executed through the diagram representation of the Intensity-Relation-Matrix. To create this diagram, the menu point of the sheet Statistics/ Intensity-Relation-Matrix/ is to be chosen. The Intensity-Relation-Diagram in the main window will be updated only after the menu Diagram/ Update diagram or if the icon diagram is chosen.
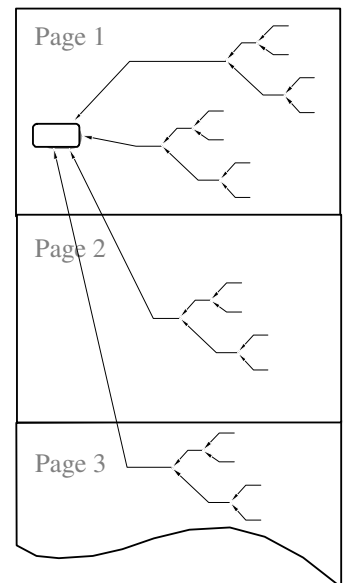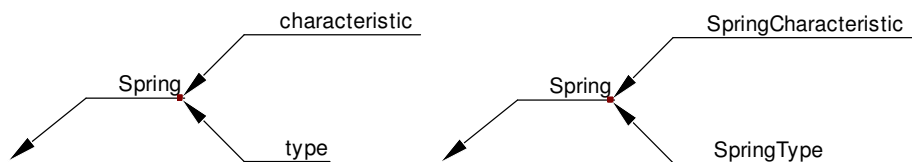
Useful tips

Representation of great structures

In Visual-XSel the sheet format to be recommended for effect diagrams is A3 landscape format. A subdivision on several sides is necessary for big diagrams. Besides, it makes sense in regard to the printout of the sides, to place main effect branches on the following sides. This could look possibly like shown on the right side.
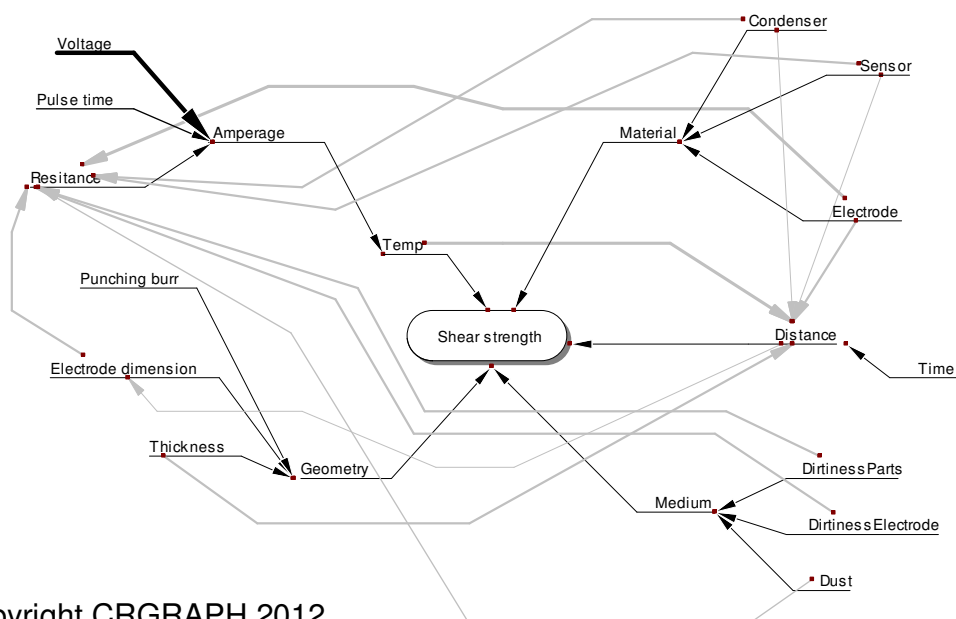
Tips for titles

With the creating of the Intensity-Relation-Matrix or a direct takeover in an experiment it is recommended to define the titles in the text arrows of the border area regarding a parameter name which is distinguishable and has a basis to the subject.

Use as a title not items like assembly or manufacturing. use the physically consequences of the assembly and manufacturing (e.g., tolerance) and assign this to the attributes of the components.

Many connections

Because of more clearness, it is an advantage to show connections in grey and put them in the background. In particular if a lot of connections exist, a thick network of lines which becomes too much complex. By the grey colour the direct effects of the text arrows remain in the foreground..

Creating an Intensity-Relation-Matrix from a structure

If parameter lists or arrangements already exist, these titles can be taken over as a parameter for the Intensity-Relation-Matrix. After marking the suitable area in the sheet the menu point of the spreadsheet *Statistics/Intensity-Relation-Matrix/Create from list or structure* is to be used. In a list with insertions this will be interpreted as an active structure. The following example:

Structure		List with insertions
1.	Amperage	Amperage
1.1	Resistance	Resistance
1.2	Voltage	Voltage
2.	Friction	Friction
2.1	Grease	Grease
2.1.1	Medium	Medium

	Am	Re	Vo	Fr	Gr	Me
Amperage						
Resistance						
Voltage						
Friction						
Grease						
Medium						

At first a square matrix is generated with the same titles in the first row. On account of the arrangement or by insertions white fields will be set (every blank is interpreted as an sublevel). White fields must be estimated with effect values.

Import from MindManager®

Very popular software for structural diagrams is the MindManager. Out of this graphics the titles can be exported as unicode text.. For this use the menu *File/Save as* and choose the file type *Structure - Plain Text*.
Because of the unicode text format this can not be imported in Visual-XSel directly . Use first notepad or Word to transfer the text via clipboard an copy again to Visual-XSel. For instance the following example:

```
=====================
 Pricipal topic
=====================

---------------------
1 Main branch
---------------------

1.1 Sub branch 1

1.2 Sub branch 2
```
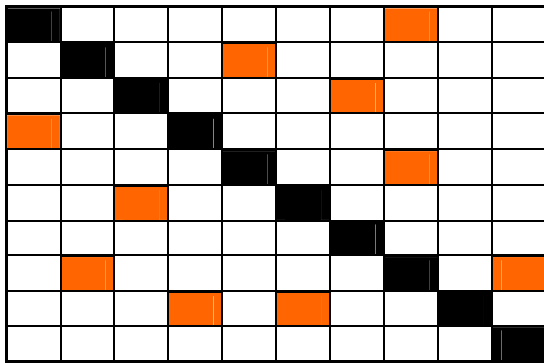
The separation lines are automatically ignored
by the production of an Intensity-Relation-Matrix. Nevertheless, like with the example with the wear the main topic is not to be taken over. Therefore, only the text area from main branch is to be transferred into the clipboard
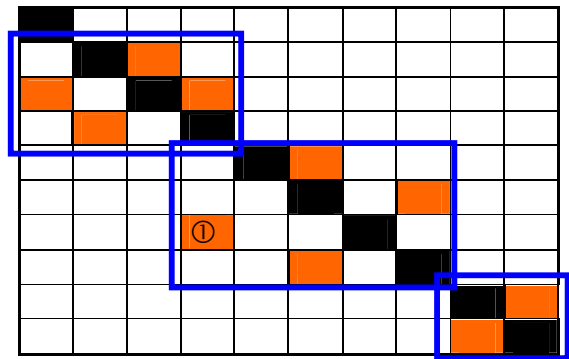
Import from IQ-FMEA®

IQ-FMEA is a powerful tool, while also effect diagrams can be provided. However, a direct export as a text file is possible only about HTML files (also here the transference is at first, e.g., in Word)

Building groups in the Intensity-Relation-Matrix

In particular with an unstructured list of parameters from a brainstorming and without effect-diagrams there are random distributed effect structures (red fields effect>0, see left matrix). The question is whether by a better arrangement of the parameters or their order possible independent groups can be found. This has a big meaning to find out which groups can be examined perhaps for themselves only, e.g., by experiments.

Intensity-Relation-Matrix
Input Information

Rearranged order with
possible independent
groups

Use in the Spreadsheet the menu Statistics/ Intensity-Relation-Matrix and the Rearrange….

With the method cluster analysis very coherent independent groups can be formed (see frames in right table). The purpose is to carry out with it investigations in smaller unities which can be controlled easier. Of course there are really always overlapping. However, this means only that some parameters are to be taken into consideration in different single investigations at the same time.

For example, the temperature has an effect also in the group on the top left, as well as in the middle (Field ① in the middle group).

The shown menu point is to be chosen to achieve these groups. After the rearrangement of the order, the respect matrix looks absolutely differently than before (the result stands in sheet „IntGroup"). However, generating the Intensity-Relation Diagram the result must be the same after the rearrangement.
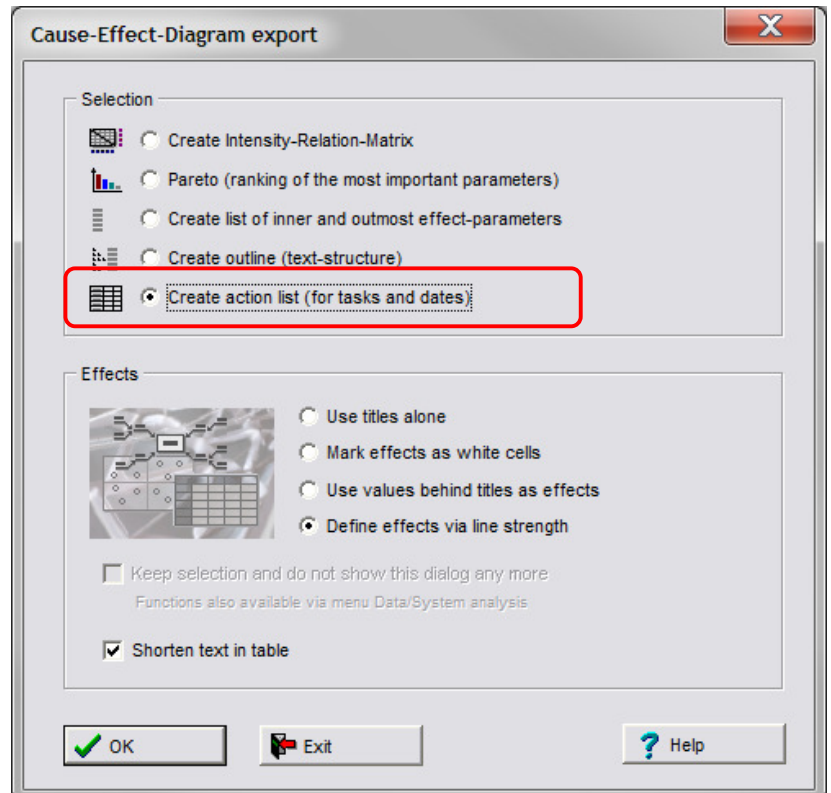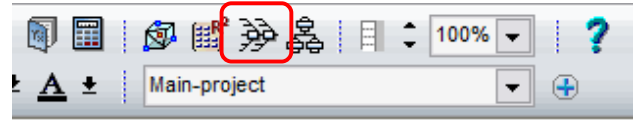
Creating an action list from effect-cause-diagram

The Effect-Cause-Diagram is also an ideal representation for systems to be examined and for the working steps derived from it. Via the Icon *System analysis* of the main window a list can be generated by working points.

The order of this list is built up in the same way like for text-structures. With it the basic structures of the main branches are also represented. The titles are numbered serially in the first column. The further columns can be defined free. Default titles are priority, investigation, responsible, date and results/ comments.

The priority is built optional from the Intensity-Relation-Matrix. Therefore this has to be generated new or must be updated. It is an great advantage here if the effects are defined via the line strength. From the Intensity-Relation-Matrix there are calculated the active and passive sum. With these the can be defined a weight factor which is: weight = 3*active+passive. This weight delivers a ranking of the titles. This one with the highest weight gets the priority 1. The next one gets the priority 2 and so on. With it the temporal sequence of the investigations can be also fixed. For example the following action list is possible:
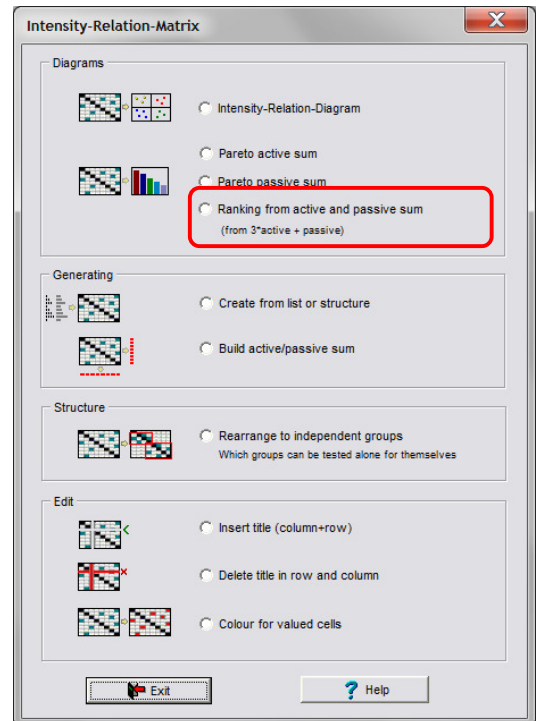
	A	B	C	D	E	F	
1	No.	Title	Prio	Investigation	Responsible	Date	Result/remark
2	1	**Material**	9				
3	2	Sensor	5	Measurement test procedure A	Smith	mm/dd/yy	
4	3	Electrode	1	Measurement test procedure A			
5	4	Condenser	5				
6	5	**Medium**	9				
7	6	Dust	8	Test camber			
8	7	DirtinessElectrode	7				

Ranking from the active and passive sum

Via the menu Statistics/Intensity-Relation-Matrix pareto diagrams for the active and passive sum can be created.

A summary from both sums shows the Ranking-Pareto. For this there is needed a weight factor: Weight = 3*active + passive. The ranking arising out of this is the reverse order of the priority of the action list (important factor stands with the highest number or weighting in front).

It is to be noted that before using this represen-tation the spreadsheet table must show the current Intensity-Relation-Matrix.

Creating an experiment

From an effect-diagram or an Intensity-Relation-Matrix an experiment can be created directly., Via the icone *Experiment* or the menu *Data/Experiment* the following dialog appears.
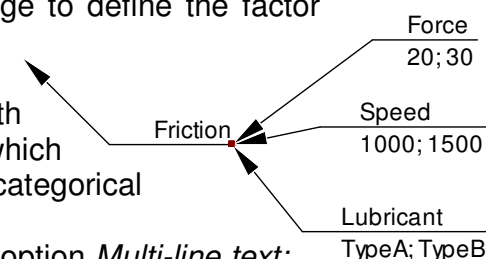
It is possible to define factors in a table. So experiments made by other applications can be imported. With this option an afterwards edited factor list can be also taken over from an arrangement of an effect diagram. However, besides this possibility the systematically reduction of insignificant factors gets lost. If the experiment from an effect diagram is provided, connections can be taken over directly as interactions.
Attention should be paid to the difference between effects and interactions (see 1st part). Under the rubric *Design* in the dialog box *Experiment* the interaction model is selected.
In the list on the left there appear interactions only where connection arrows in the graphic exist. If the option *Interaction* is clicked once more all pairs of factors will be used as interactions. This is also the fact if the model *Quadratic* is chosen (or higher models). Because of this a quadratic model should be selected in the above dialog box. The effect is that here only quadratic terms and the graphically defined interactions will be used.
If in the structure changes arise, it is an advantage to define the factor levels (range) directly in the graphic (see example on the right). These are to be written in a new line under the title. Values has to be separated with semicolon (without units). Text definitions which contain not values are i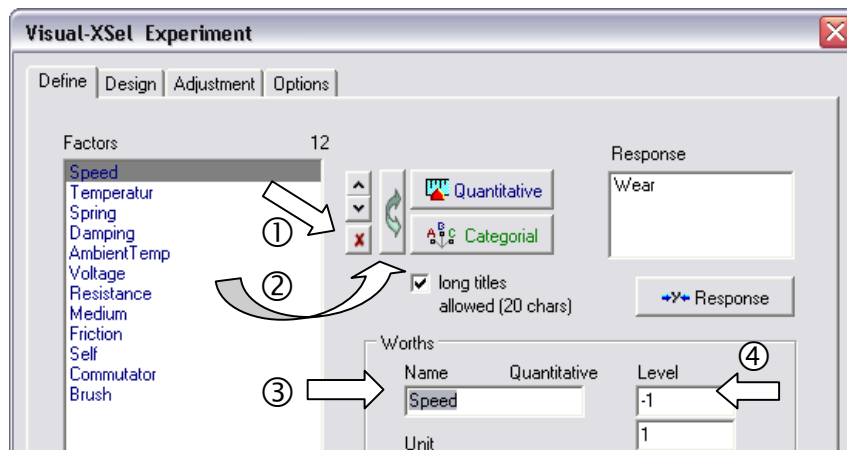nterpreted as categorical expressions. To use this for an experiment, there must be selected the option *Multi-line text: Range or categorical expressions* in the above dialog box. Please note, that not independent factors possible can not be adjusted on all levels in the test. Therefore, these factors can be used only if the value areas can be achieved under test conditions with appropriate devices, or can be simulated.
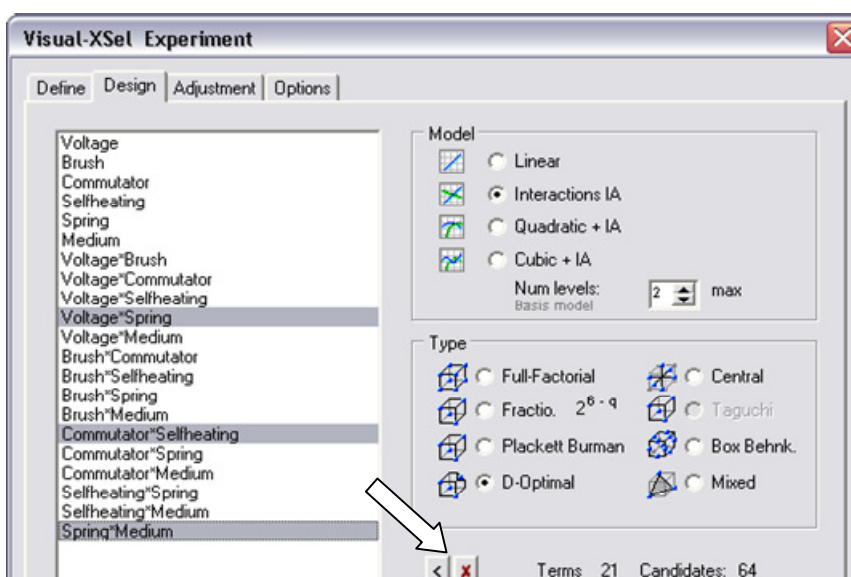
The best way is to define an experiment with the method of the Intensity-Relation-Diagram.
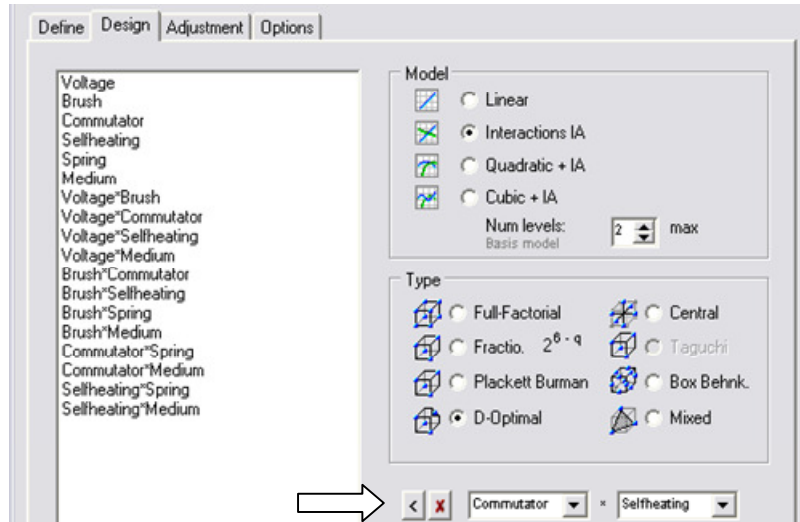
For the next steps the infomation in the spreadsheet page *#Int* will be used. The base selection is to take over only all factors in the *Active* and *Critical* field. Through this a sensible reduction of the factor number arises. Perhaps dependent factors which are determined by others are in the choice of the factors. These should be deleted ①. If there is a factor a categorical expression, this can be changed under ②.

Also factor names and the level can be changed in the panel ③ and the list ④. If chosen interactions from the critical field, all combinations of factors in this field will be used, and additional also all combinations between factors in the critical and the active field. On the other side, combinations of factors in the active field will not be taken over. Often there exist also interactions between factors in the active field. Nevertheless it makes sense to use all Interactions. Technical not useful combinations can be deleted with the button which is shown on the dialog box below:

Through the button *Insert interaction or quadratic term* ⟨ , it is possible to select again deleted terms.

Select the factor partners in the choice appearing then and click once more the button ⟨ . If both factor titles are the same, one generates a square term, e.g., spring^2.

Via this described proceeding one can separated actually important from insignificant parameters. By the expenditure reduction of test plans it is possible to let out the factors with the probably slightest influence. The source table for the production of a test plan is always #Int, no matter whether the intensity respect matrix was generated by an active diagram, or an independently table. The renaming of the table side occurs through a double click on the suitable tabs below in the table.

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