



Further topics are:

www.weibull.de/COM/Fault_Tree_Analysis.pdf

www.weibull.de/COM/Design_of_Experiment.pdf



Keywords: System-analysis – Structure – DoE – Cause-Effect – Pareto – Intensity Relation Matrix

Introduction

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 Six Sigma.

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

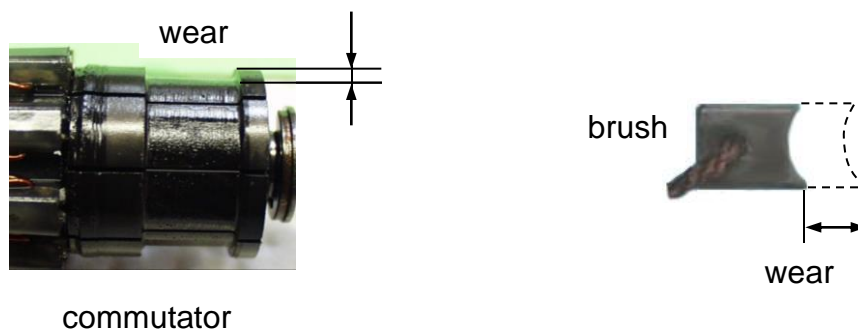
Purpose and benefit

Design of experiments often fail because of the insufficient preparation. The best statistical methods cannot recognize underestimated or forgotten factors. The goal of a system analysis is to identify and prioritize the right influencing parameters. The less important ones can be omitted and thus reduce the experimental effort.

Basics

The block- or structure 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.

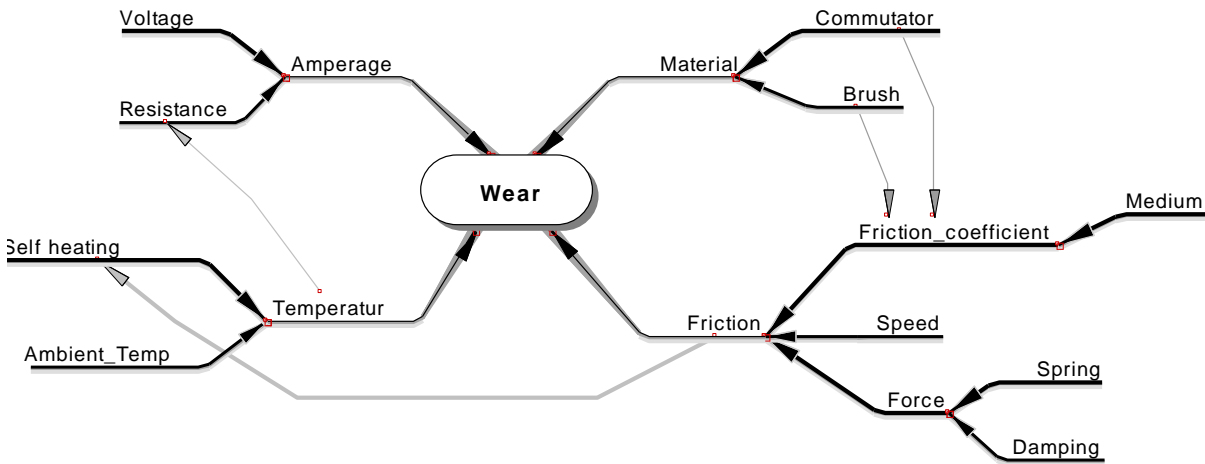
A substantially better possibility for solving problems is to put the error pattern in the foreground. The procedural method should be described on the following example. In the development of a new engine there was a wear problem in commutator and brushes.



If one uses here instead of the components physical / technical issues for the causes

System Analysis

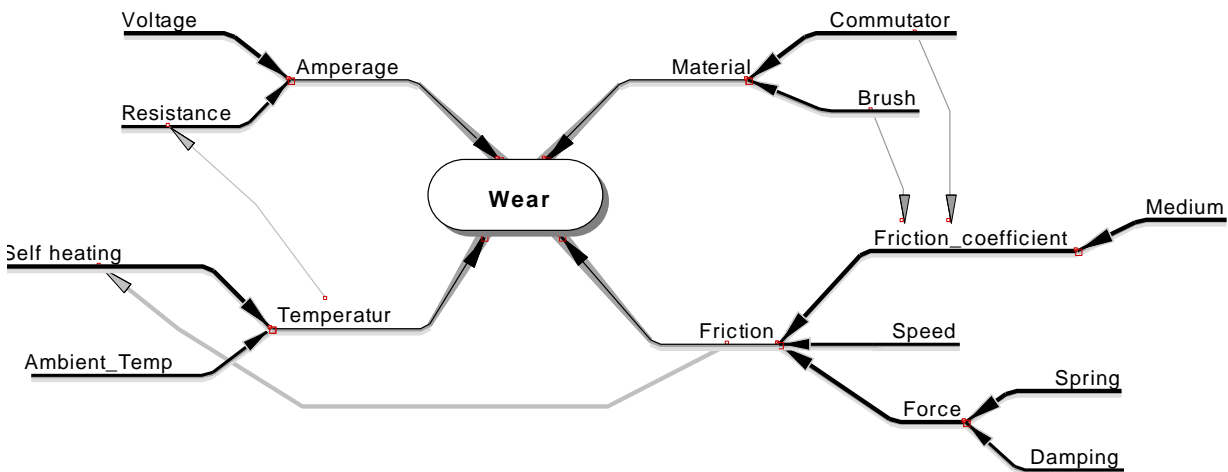
of wear, there can be shown the following possible simplified representation:



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 cross connections (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 cross connections:



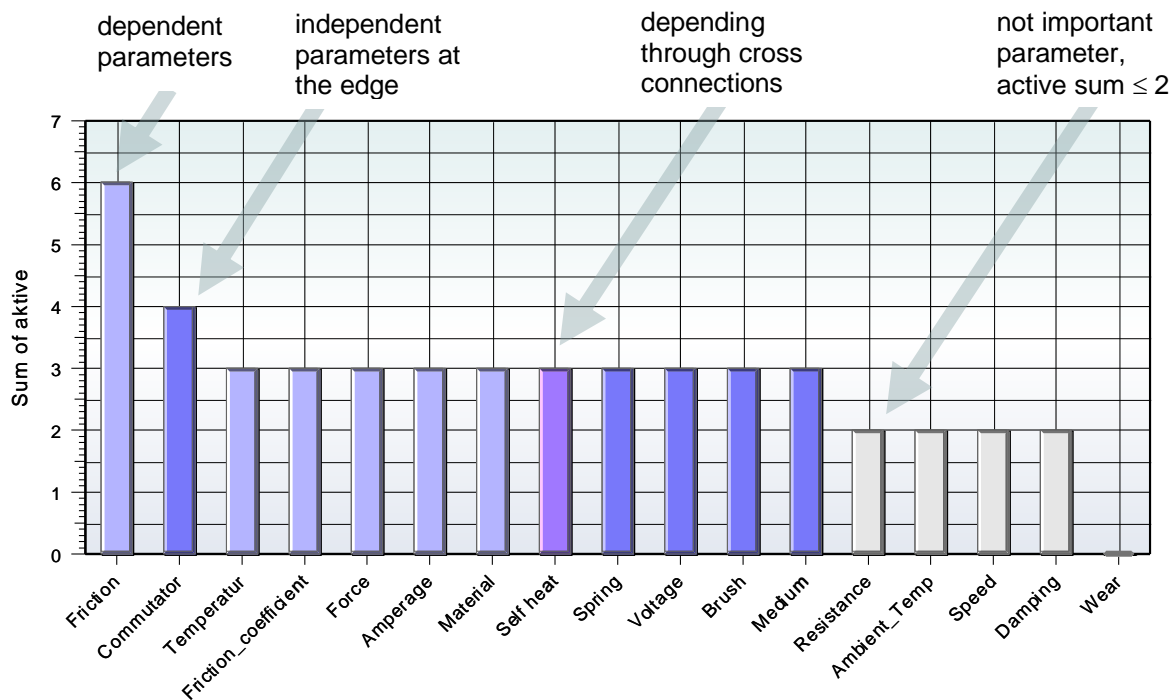
The next step is the assessment of the Cause Effect Diagram usually by experts or specialists in the following gradation of weights:

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

Sometimes it is necessary to use a 5-level value for top effects of main factors. Do not use 9 for this method, because this value will jut out all other effects.

The effect strengths are given for the structure as well as for the cross connections. In the diagram, these strengths are highlighted by thinner or thicker branches and cross connections. This is important for the subsequent evaluation. For example, the friction has an active strength of 3 and the outgoing cross connection also. Therefore the friction has in total 6 points. This is a great advantage of this kind of system analysis, since the friction has a physical effect via two paths. This would not be considered by using only the simple basis diagram shown at the beginning.

Pareto distribution – ranking of the most important factors



For a DoE, only parameters on the edge can be used, because those do not depend on others. These are marked in the Pareto diagram in dark blue if the evaluation sum is > 2.

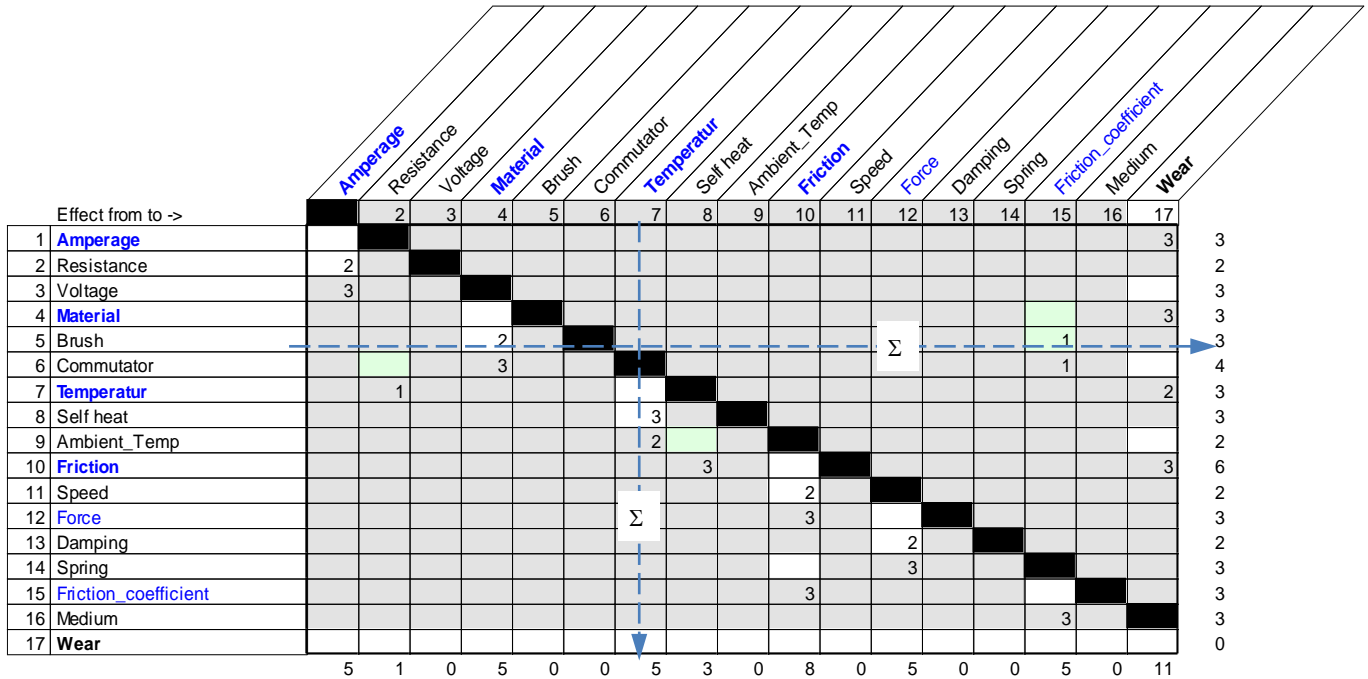
If parameters are estimated too low and are important in the active chain, this parameter should be still used nevertheless. An example of this is the friction (first title in Pareto). This is among others dependent on the spring strength. If, instead of 3 the estimation having only 2, the spring strength would not have been selected in a parameter selection. Due to the importance of friction, one must consider the actual causer.

Alternatively the Cause Effect Diagram can be evaluated by a so-called Intensity Relation Matrix.

System Analysis

Intensity Relation Matrix

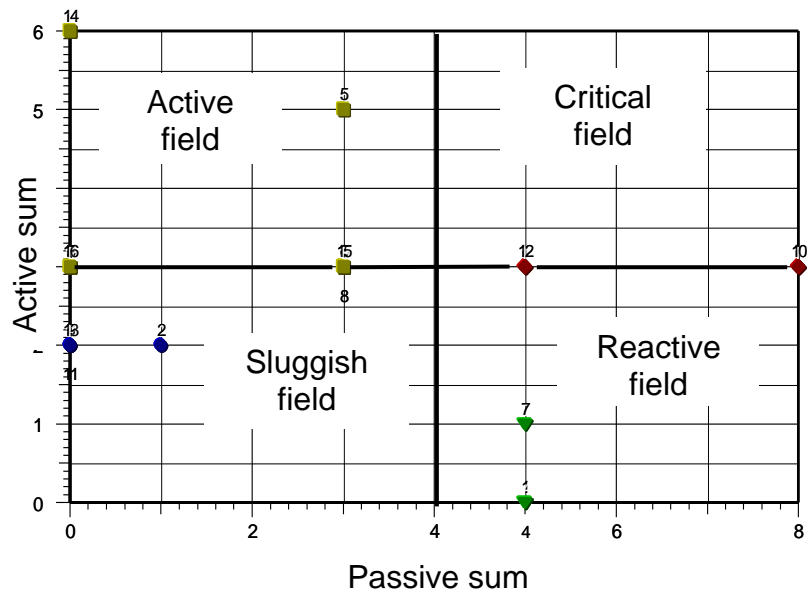
The following possible matrix arises from the Cause Effect Diagram with considered cross connections:



White marked cells mean that direct effect (arrows) exist in the Cause Effect Diagram. Light grey fields are cross connections (cross arrows). Those fields must be evaluated in each case. The dark grey fields are to be checked again whether here effects were overlooked. Maybe some cross connections were forgotten.

After the assessment (weights) 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 (air conditioning). The title is simplified to temperature.

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

$6 \cdot (6-1) / 2 = 15$ possible interactions.

These are:

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

Voltage*spring, commutator*temperature (self-heating) und spring*medium make no sense and will be taken off. Therefore further 3 interactions can be saved additionally. The minimum number of tests for D-Optimal design from this action is now:

$$n = 6 + 15 - 3 + 1 + 1^* = 20$$

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

$$n = 10 + 10 \cdot (10-1) / 2 + 1 + 1^* = 57$$

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

Compared to the complete design we can save 37 terms and thus 37 experiments.

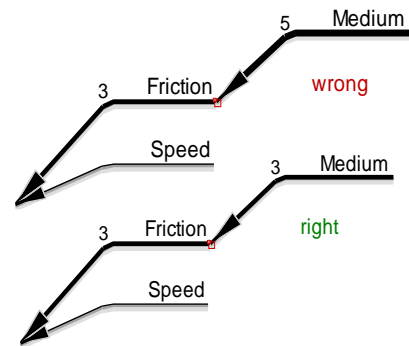
The essential point with this example is that the assessment has not occurred only between the independent factors (factors in the border area of the Cause Effect Diagram). Rather the dependent dimensions amperage, temperature, friction and material were also incorporated. An assessment focused on the 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

Assessment layout

The weights refers normally to the respective successor. If the medium would have a weight of 5, but the friction has only a weight of 3, the medium is overestimated concerning to the importance of the main title. At the end the last branch is physically decisive for wear. The outside branches must have therefore lower or equal weights than the inner branches, in this case a maximum of 3.



Disproportionate very active factors

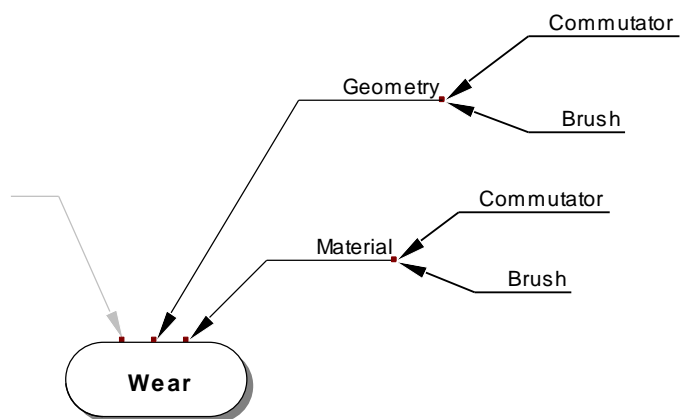
Sometimes it can be that a factor shows an active sum very high by far and perhaps passive sum towards other. The axis area is determined by this factor and all the other factors appear almost only in the passive field. Then the described division in four fields and their interpretation does not make 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.

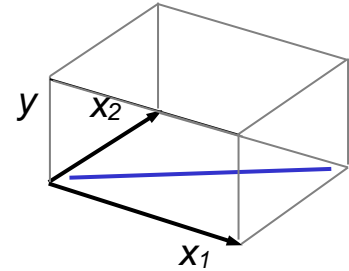


Cause effects versus Interactions

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

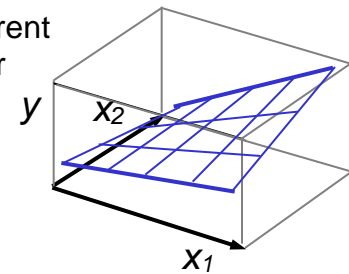
Cause effects (evaluation in the Intensity-Relation-Matrix)

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.

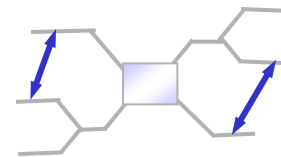
Cross connections in the Cause Effect Diagram

if this represent cause effects:

⇒ Further analyses via Intensity Relation Matrix

if this is defined as interactions:

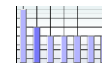
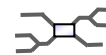
⇒ Direct definition for test-plan



Summary action plan

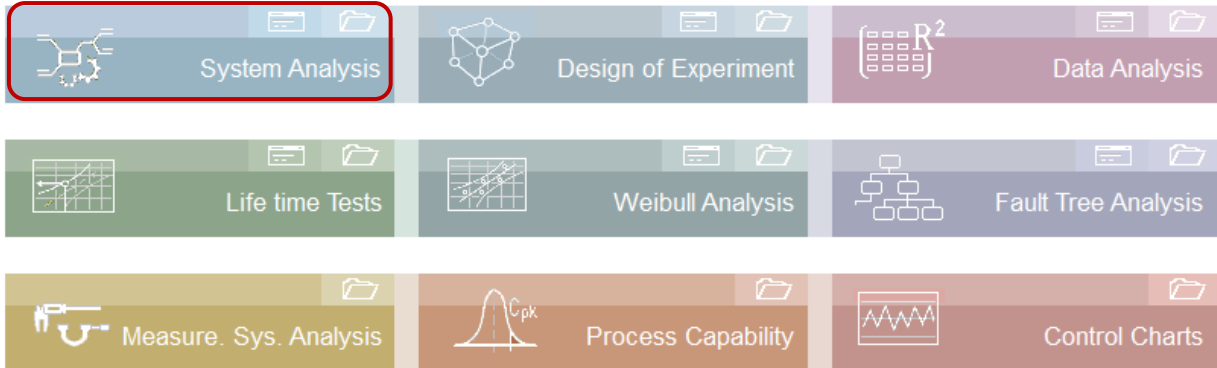
To summarise one can define the following 4 steps of the systems analysis up to the test plan

- 1 Identification of the physical dimensions and factors by brainstorming.
- 2 Graphical description as structure- and Cause Effect Diagram
Consideration of the cross connections
- 3 Create the Pareto diagram and select the most important parm.
- 4 Create a test plan (Design of Experiment)

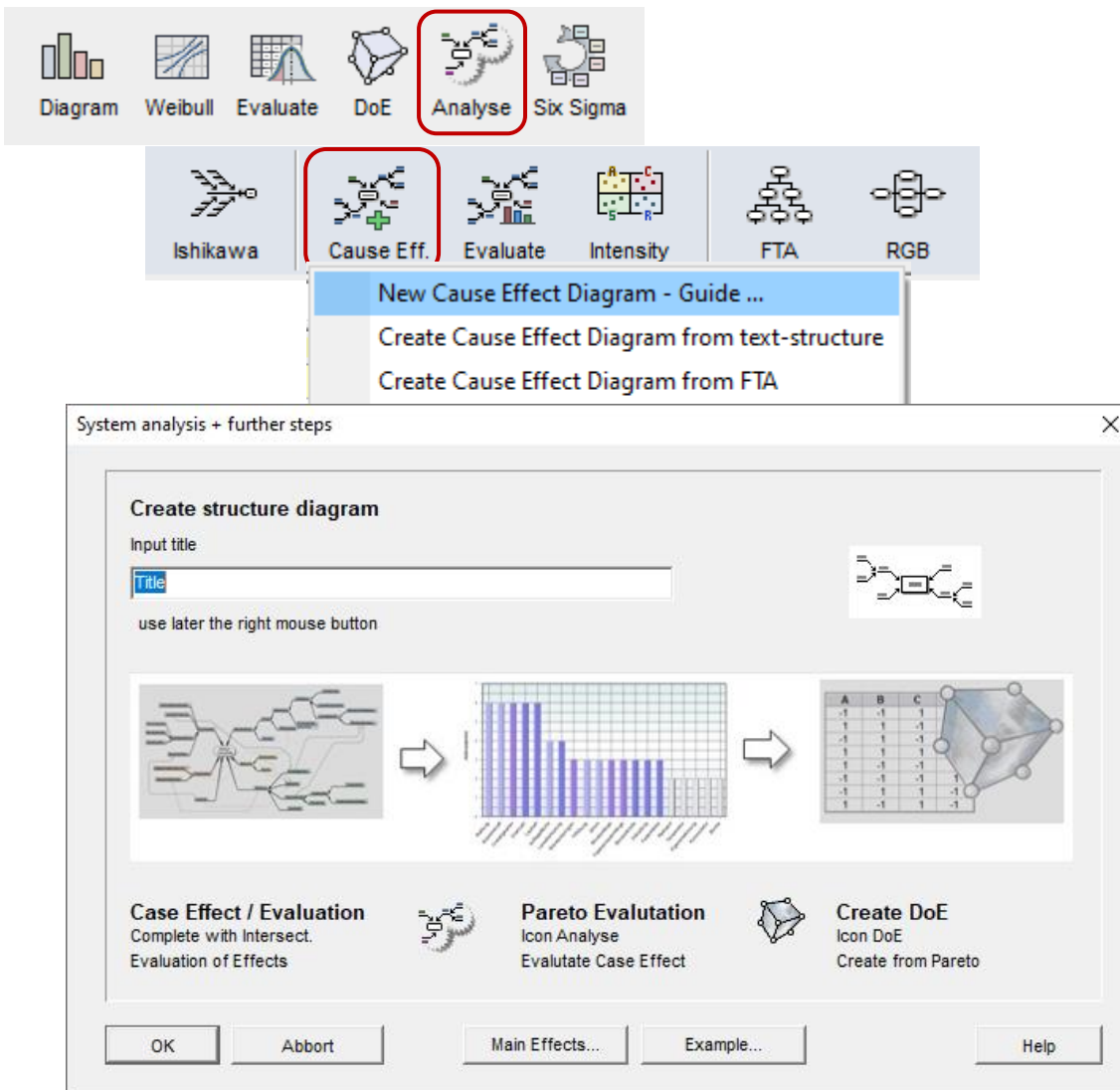


Often the first and second step is combined. But the recommendation is to make a brainstorming first. Otherwise the creative process is steered too much in a certain direction.

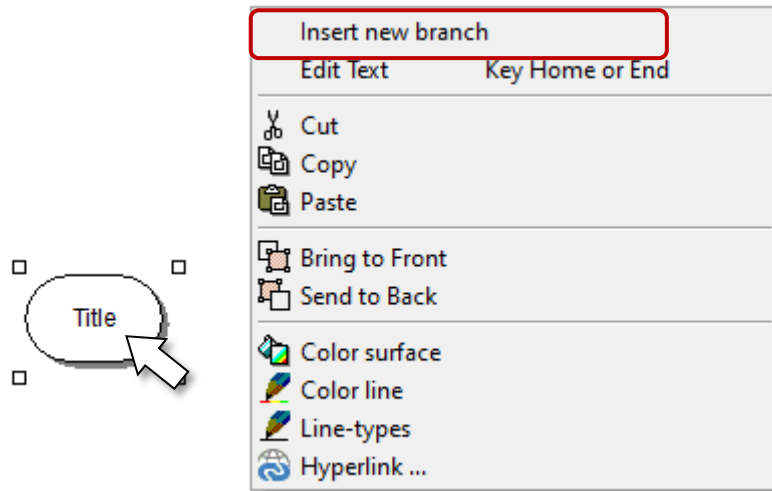
Program instructions Visual-XSel



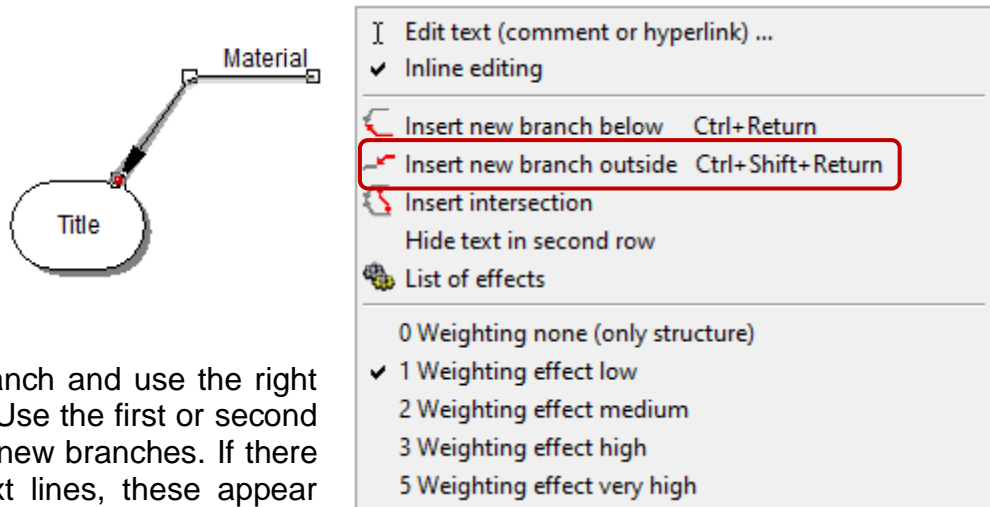
In Visual-XSel structural diagrams, as well as systems analyses can be carried out via:



At first a structural, 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. Click to the oval title and use the right mouse button.



Type a text on the branch



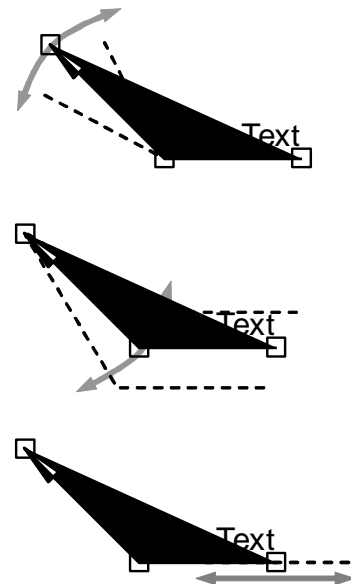
Click to the branch and use the right mouse button. Use the first or second menu to insert new branches. If there are several text lines, these appear below the line.

The position of the middle clip is where the mouse pushed up after moving.

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.



System Analysis

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 pressed at the same time. To insert a new element below time.

From these graphic representations a structure or an Intensity-Relation-Matrix can be generated (see icon Analysis – Cause Effect Diagram eval.). 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).

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

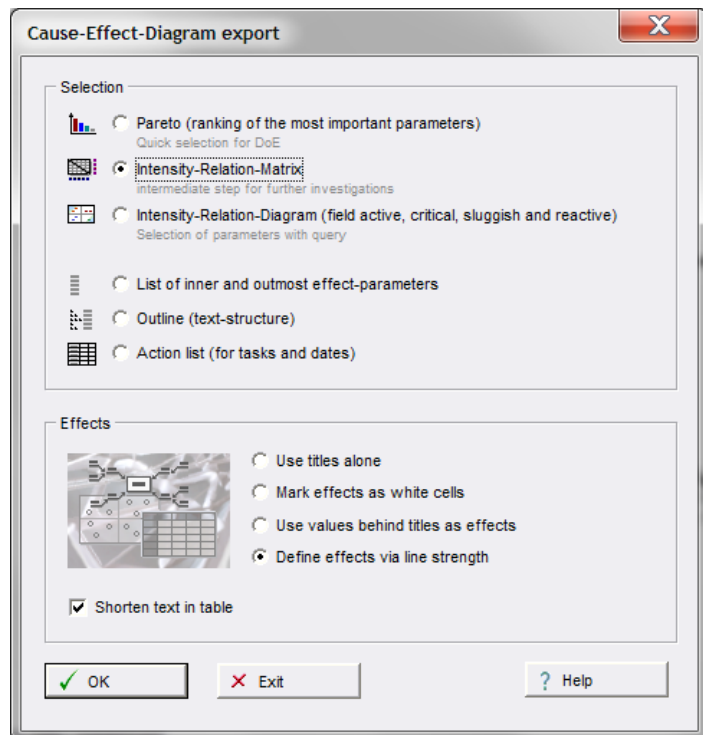
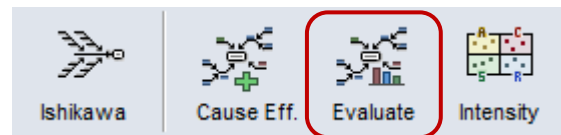
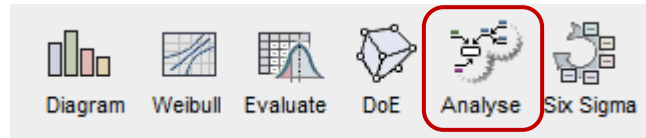
If after the assessment in the table once more changes are necessary in the structural diagram, the values are deleted by renewed generating of the Intensity-Relation-Matrix in the table!

Therefore, it is better to define the effect-weight via the line strength. See example: ..\Templates\01_System_Analysis\Effect_diagram_problem_oriented_wear.vxg.

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

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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 icon Analysis / Cause Effect + has 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.

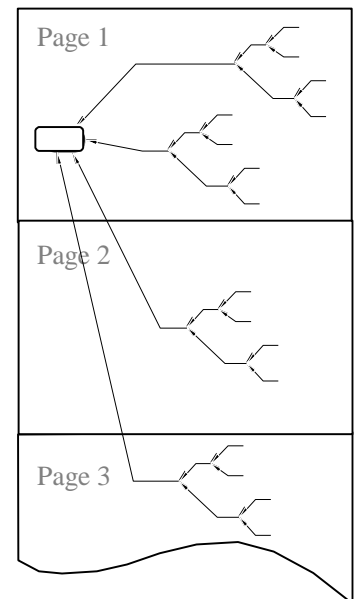
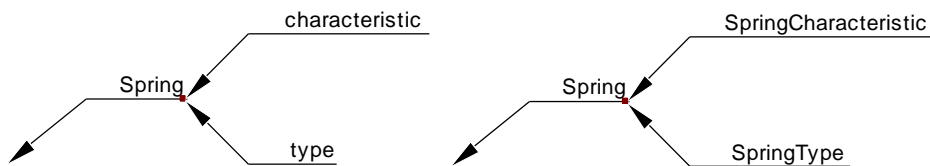
Useful tips

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

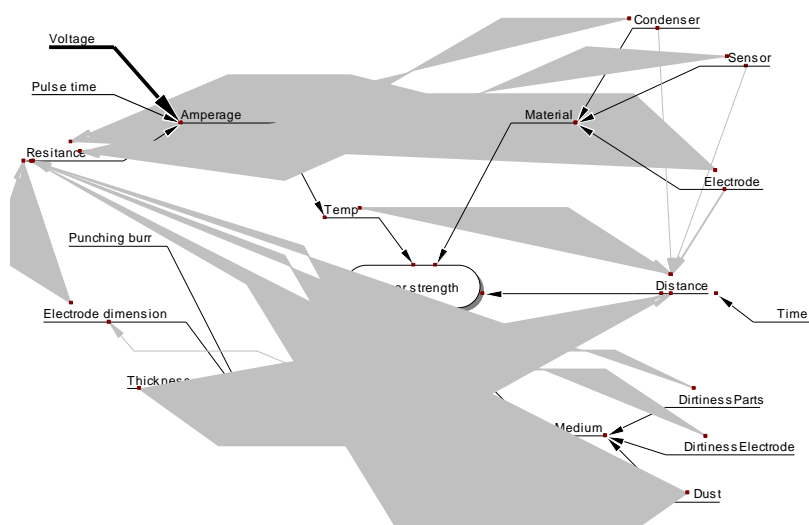
With the creating of the Intensity-Relation-Matrix or a direct takeover in an experiment it is recommended to define the titles in the text arrows of the border area regarding a parameter name which is distinguishable and has a basis to the subject.



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...

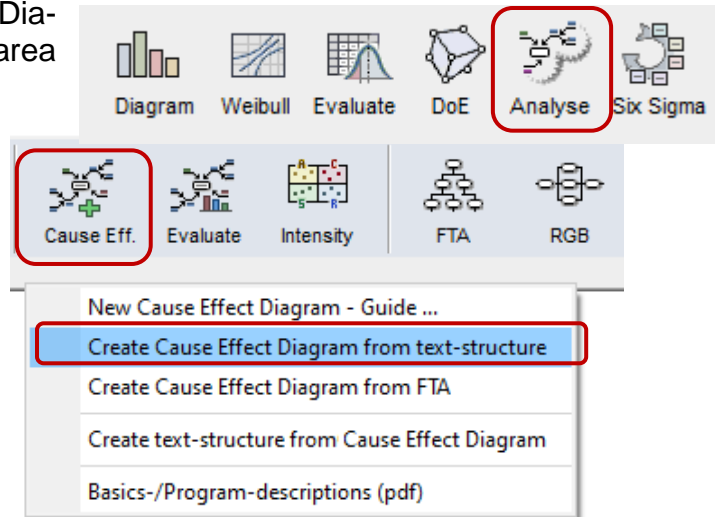


System Analysis

Creating a Cause-Effect-Diagram from a text structure

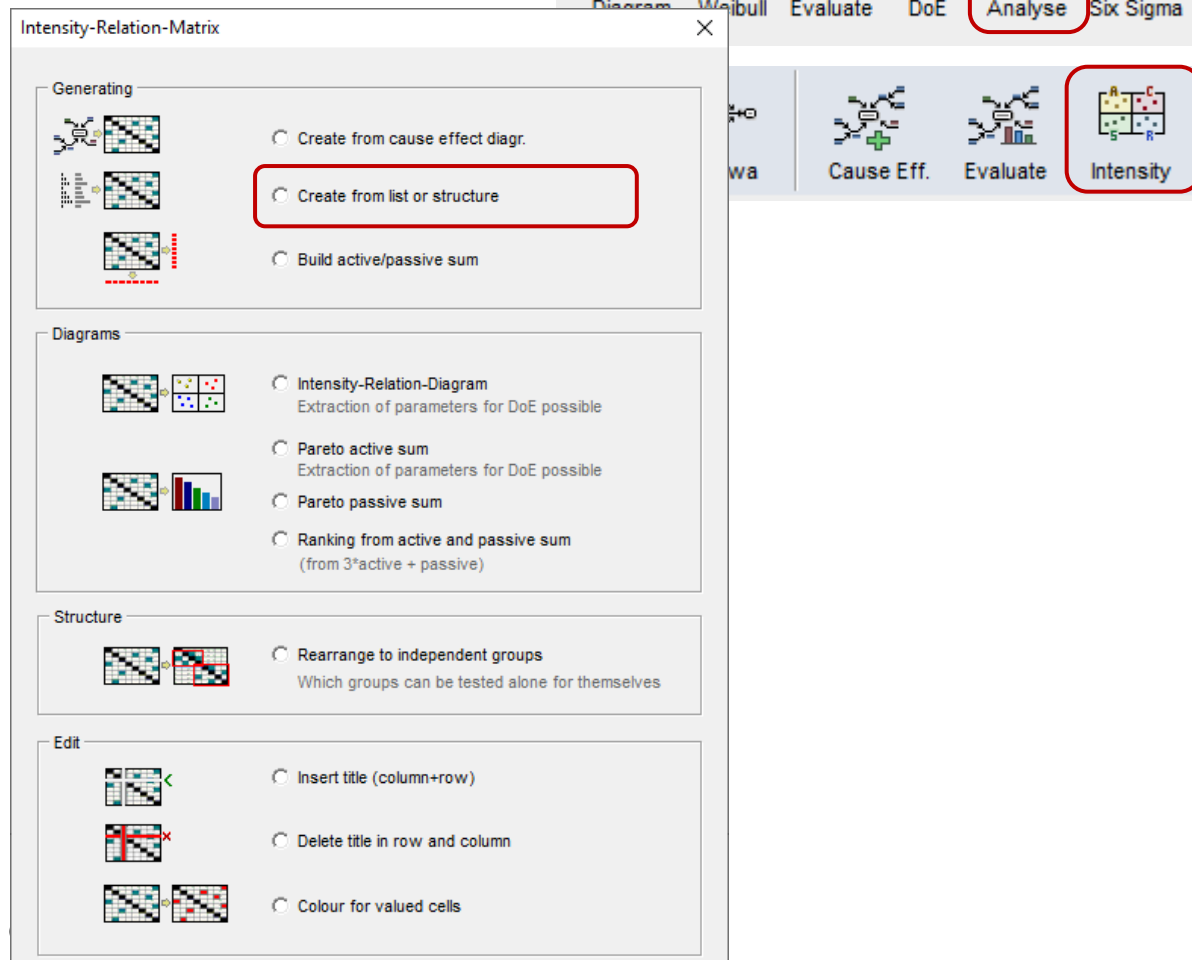
If parameter lists or arrangements already exist, these titles can be taken over as parameters for the Cause-Effect-Diagram. After marking the suitable area in the sheet use this menu point

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



Creating an Intensity Relation Matrix from a structure

In the same way those titles can be taken over as a parameter for the Intensity Relation Matrix. After marking the suitable area in the sheet use this menu point



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

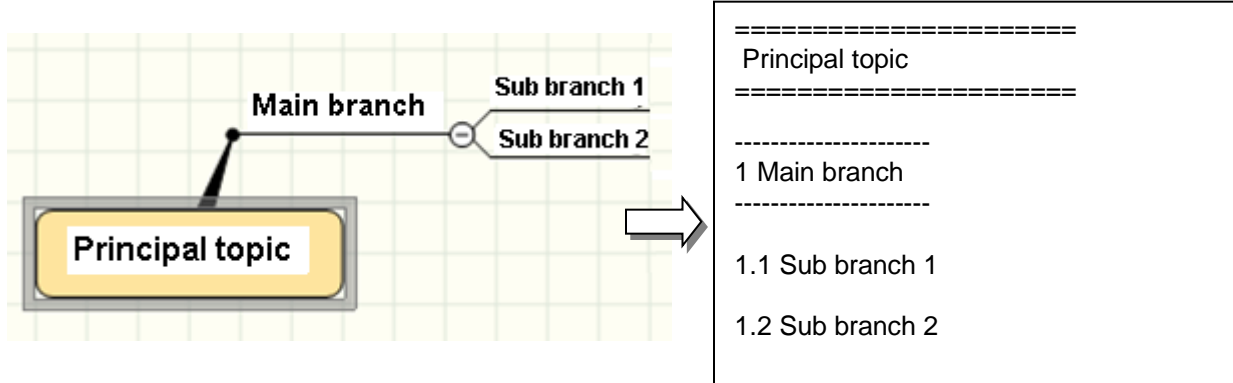
	Am	Re	Vo	Fr	Gr	Me
Amperage	■					
Resistance		■				
Voltage			■			
Friction				■		
Grease					■	
Medium						■

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 a 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 cannot be imported in Visual-XSel directly. Use first notepad or Word to transfer the text via clipboard a copy again to Visual-XSel. For instance, the following example:



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)

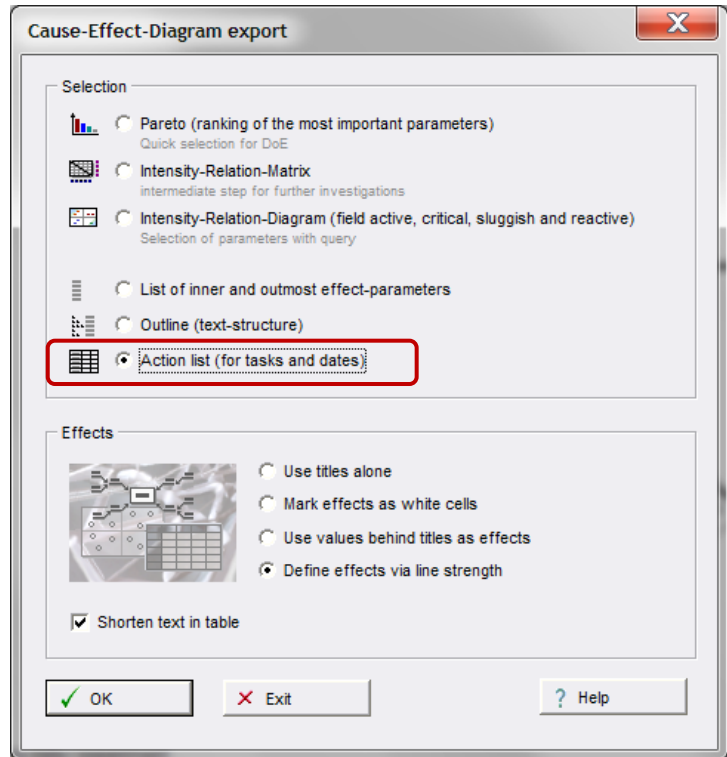
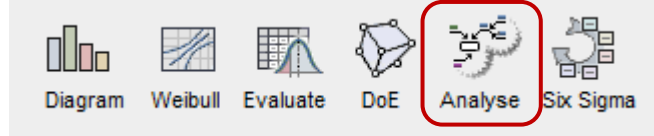
System Analysis

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.

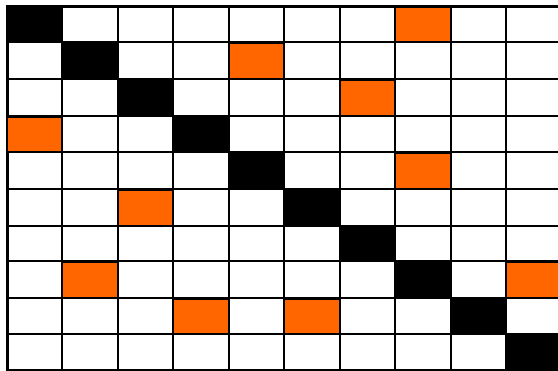
The priority is built optional from the Intensity-Relation-Matrix. Therefore this has to be generated new or must be updated. It is a great advantage here if the effects are defined via the line strength. From the Intensity-Relation-Matrix there are calculated the active and passive sum. With these it can be defined a weight factor which is: $\text{weight} = 3 \cdot \text{active} + \text{passive}$. 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:



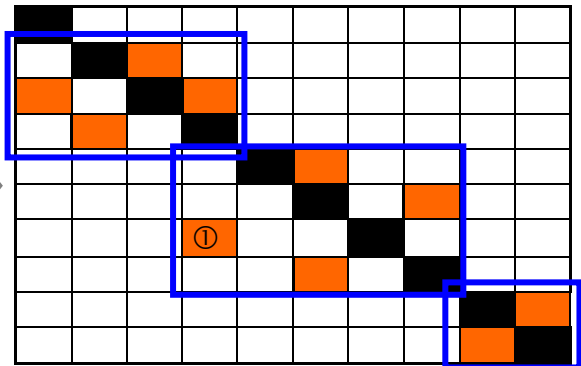
	A	B	C	D	E	F	
1	No.	Title	Prio	Investigation	Responsible	Date	Result/remark
2	1	Material	9				
3	2	Sensor	5	Measurement test procedure A	Smith	mm/dd/yy	
4	3	Electrode	1	Measurement test procedure A			
5	4	Condenser	5				
6	5	Medium	9				
7	6	Dust	8	Test camber			
8	7	DirtyessElectrode	7				

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



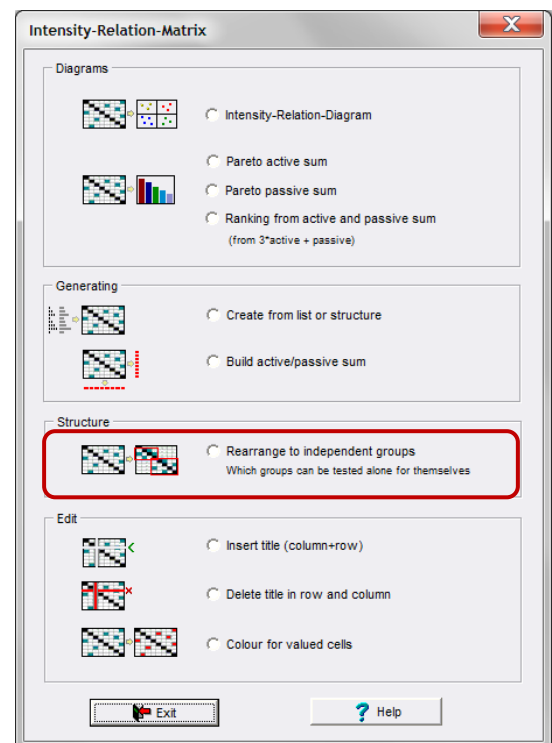
Rearranged order with
possible independent
groups

Use the icon *Analysis / 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.

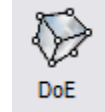
For example, the temperature has an effect also in the group on the top left, as well as in the middle (Field ① in the middle group).

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



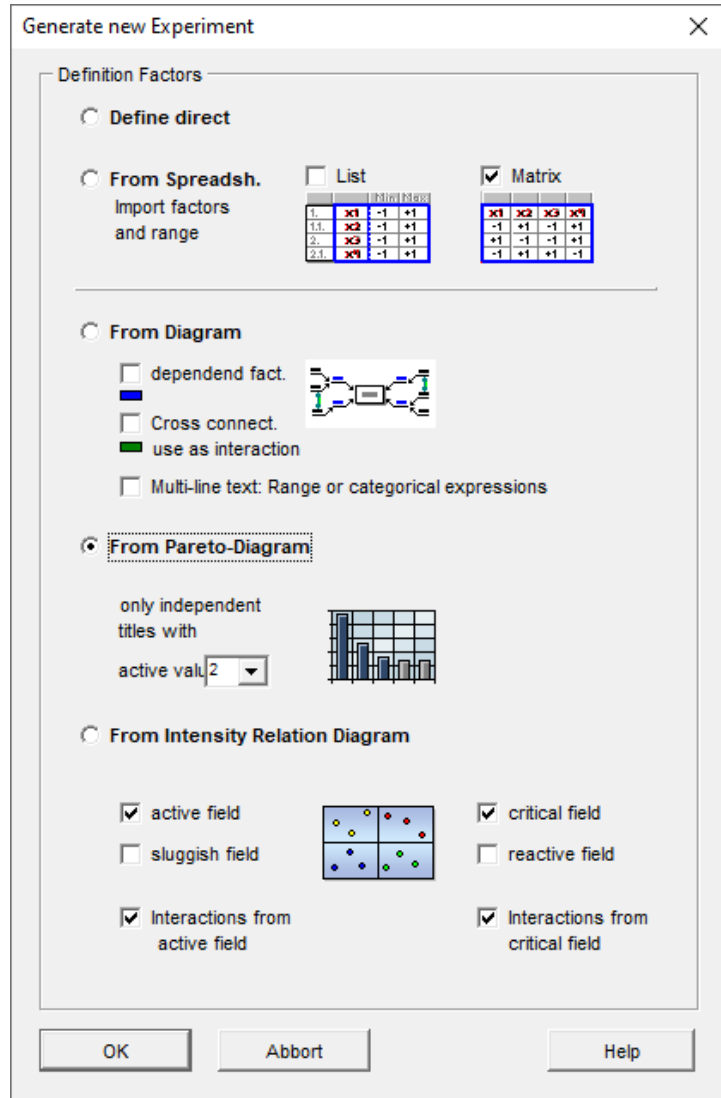
Creating an experiment

From an effect-diagram or an Intensity-Relation-Matrix an experiment can be created directly., Via the icon *Experiment* the following dialog appears.



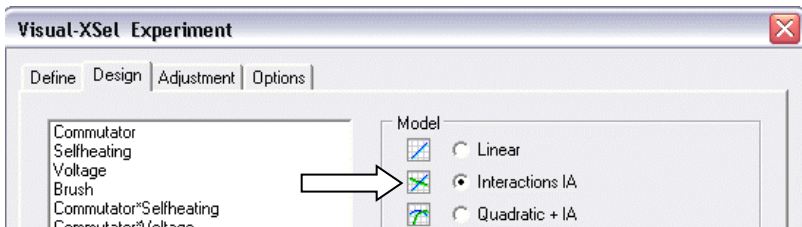
It is possible to define factors in a table. So experiments made by other applications can be imported. With this option an afterwards edited factor list can be also taken over from an arrangement of an effect diagram. However, besides this possibility the systematically reduction of insignificant factors gets lost. If the experiment from an effect diagram is provided, connections can be taken over directly as interactions.

The recommended method is to create a DoE from a Pareto-Diagram.



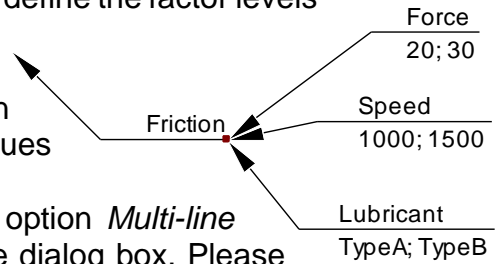
Attention should be paid to the difference between effects and interactions (see 1st part). Under the rubric

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



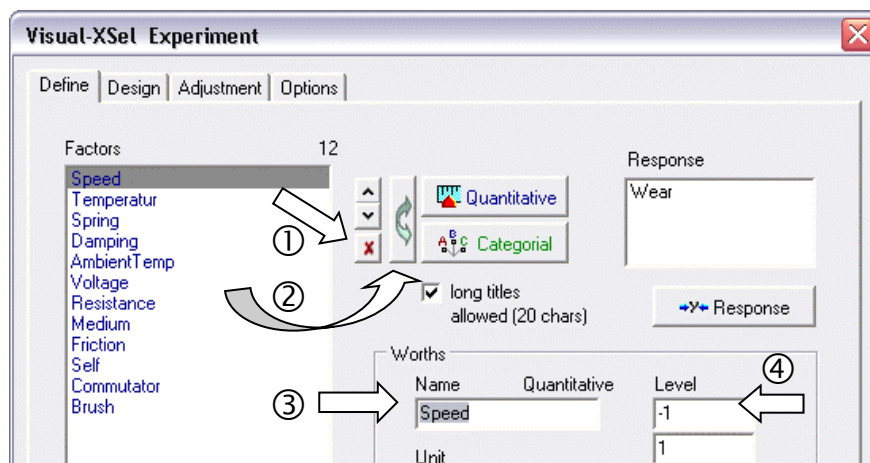
Interaction is clicked once more all pairs of factors will be used as interactions. This is also the fact if the model *Quadratic* is chosen (or higher models). Because of this a quadratic model should be selected in the above dialog box. The effect is that here only quadratic terms and the graphically 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 interpreted 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 cannot 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.



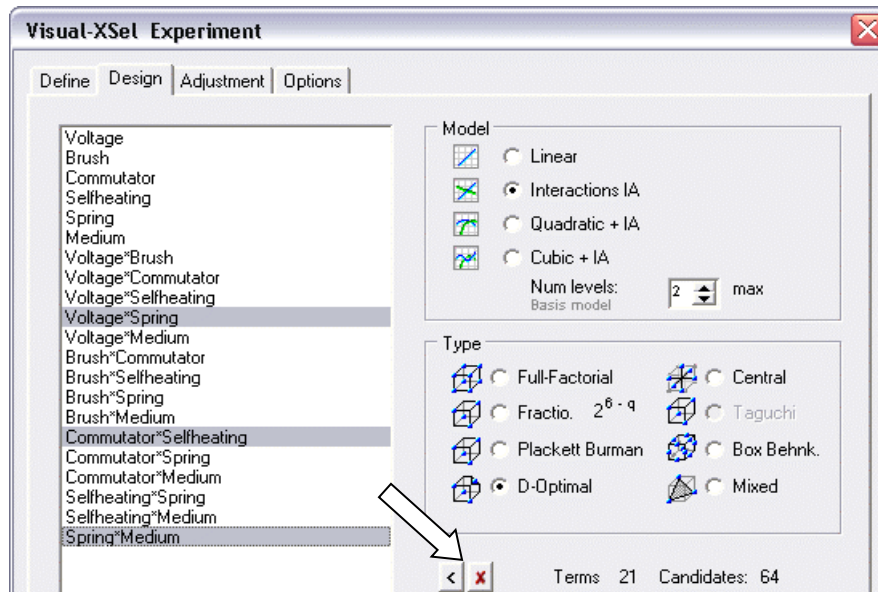
The best way is to define an experiment with the method of the Intensity-Relation-Diagram.


For the next steps the information 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.

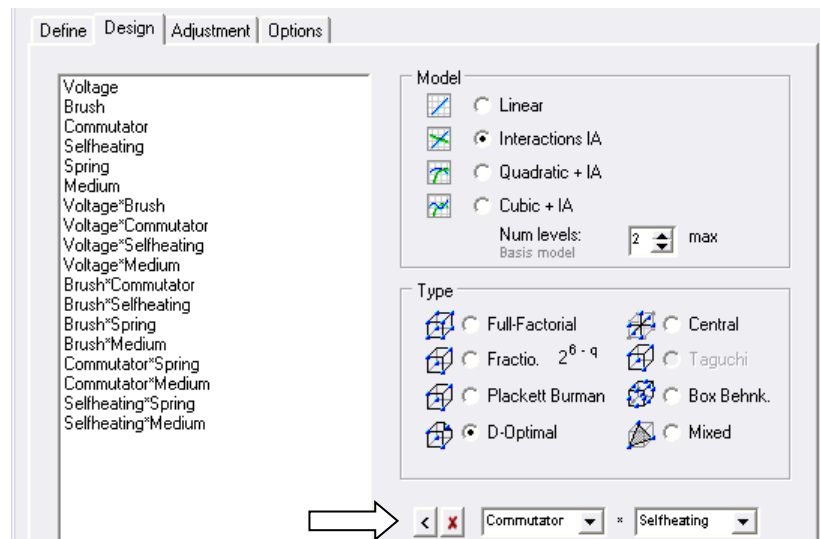



Also factor names and the level can be changed in the panel ③ and the list ④. If chosen interactions from the critical field, all combinations of factors in this field will be used, and additional also all combinations between factors in the critical and the active field. On the other side, combinations 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.

For more information about DoE see also www.weibull.de/COM/Design_of_Experiment.pdf