Ramentor Oy

ELMAS 4

Pumping Unit Example Solution

Version 1.0

Ramentor Oy
Hermiankatu 8 D
FI-33720 Tampere

Tel. +358 (0) 40 746 6585
info@ramentor.com
www.ramentor.com

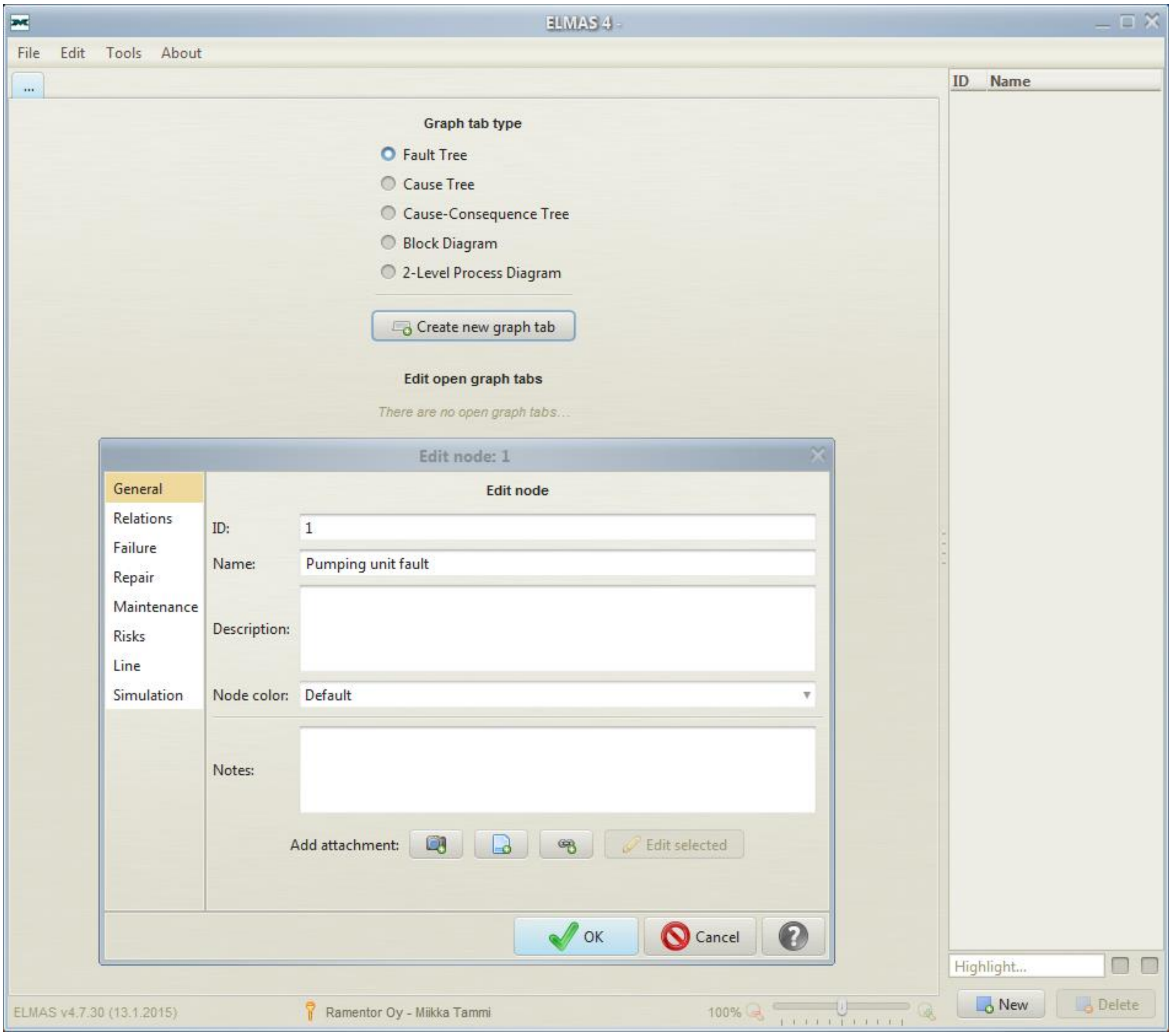
CONTENT

ELMAS – GETTING STARTED

Starting an analysis project with ELMAS:

a) Launch ELMAS 4.7 from desktop installation or by using Java web start from Ramentor Extranet (https://extranet.ramentor.com/elmas/). More details about launching the software from document: 'ELMAS 4.7 – Information and Requirements.pdf'

b) For empty ELMAS project the startup tab is shown. The modeling is started by selecting a suitable modeling method and by defining the studied entity. To solve the Pumping unit example we use Fault tree model and stochastic simulation.



c) Select *Fault Tree* graph tab type and press *Create new graph tab*.

d) Define the studied system or event (*Pumping unit fault*) by using the fields (*ID*, *Name* and *Description*) of the opened *Edit node* dialog. You can also add notes, node color and attachments if needed. Press *OK* to save edited data and to close the *Edit node* dialog.

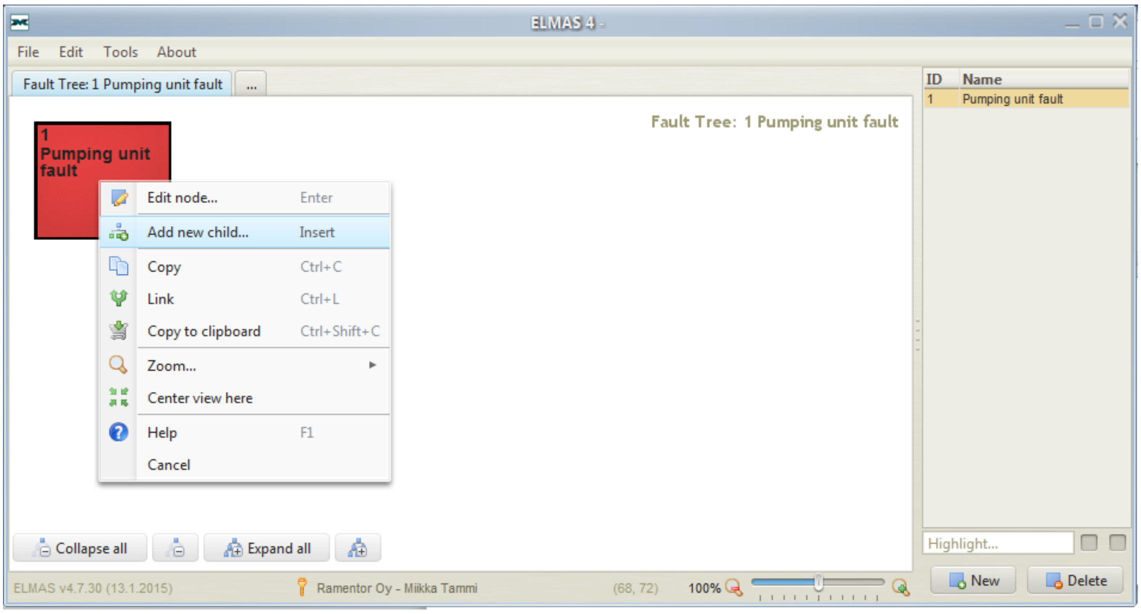
e) A Fault tree tab is created and the model with the defined node is shown.

1 PUMPING UNIT BASIC ANALYSIS

1.1 Fault Tree Analysis – Create the Cause Structure

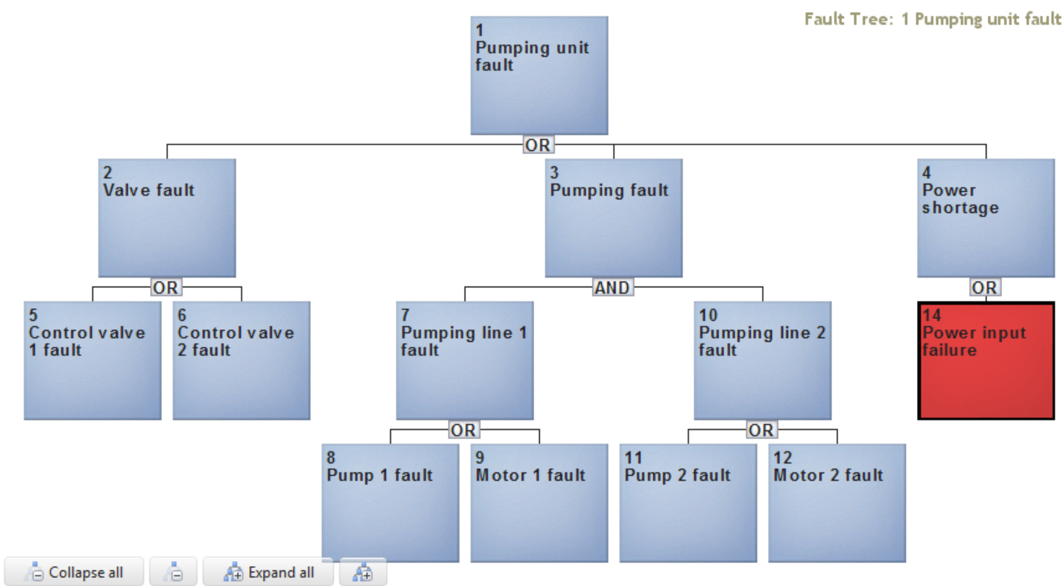
a) Think up reasons that can cause the studied event. Try to think about as large entities as possible (immediate causes). For example consider functional failures of the system before thinking specific failure modes of sub systems or components.

b) Add new (child) node for each of the previously considered causes. A child node is added by right-clicking a node of the model and selecting *Add new child*.



c) Define the added cause by using the fields (*ID*, *Name* and *Description*) of the opened *Edit node* dialog. Press *OK* to save the edited data. The child node is added below the original.

d) Continue building the fault tree model by repeating the previous steps until all the relevant causes are added to the model. The cause structure is now created.



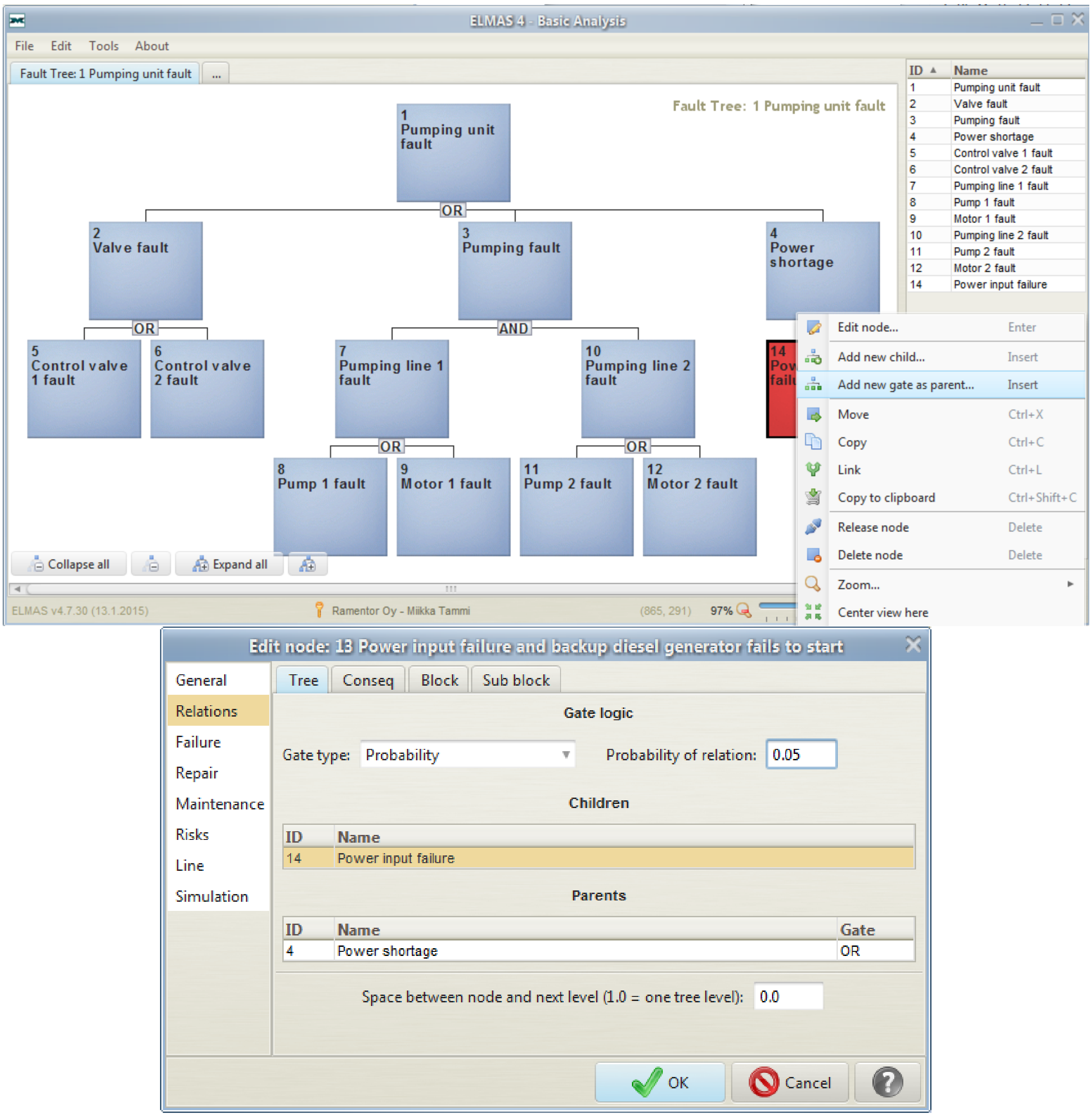
1.2 Fault Tree Analysis – Define Logic Conditions

e) Make sure that the logic conditions between the nodes of the cause structure are correct. Sometimes a single cause is enough to trigger the event (OR-logic), sometimes all the causes must exist simultaneously to make it happen (AND-logic).

f) The logic condition is defined by double-clicking the upper node to open the *Edit node* dialog and selecting the *Tree* tab of the *Relations* page. Simple logic condition changes can also be made directly without opening the *Edit node* dialog by right-clicking the relation icon (under the node).

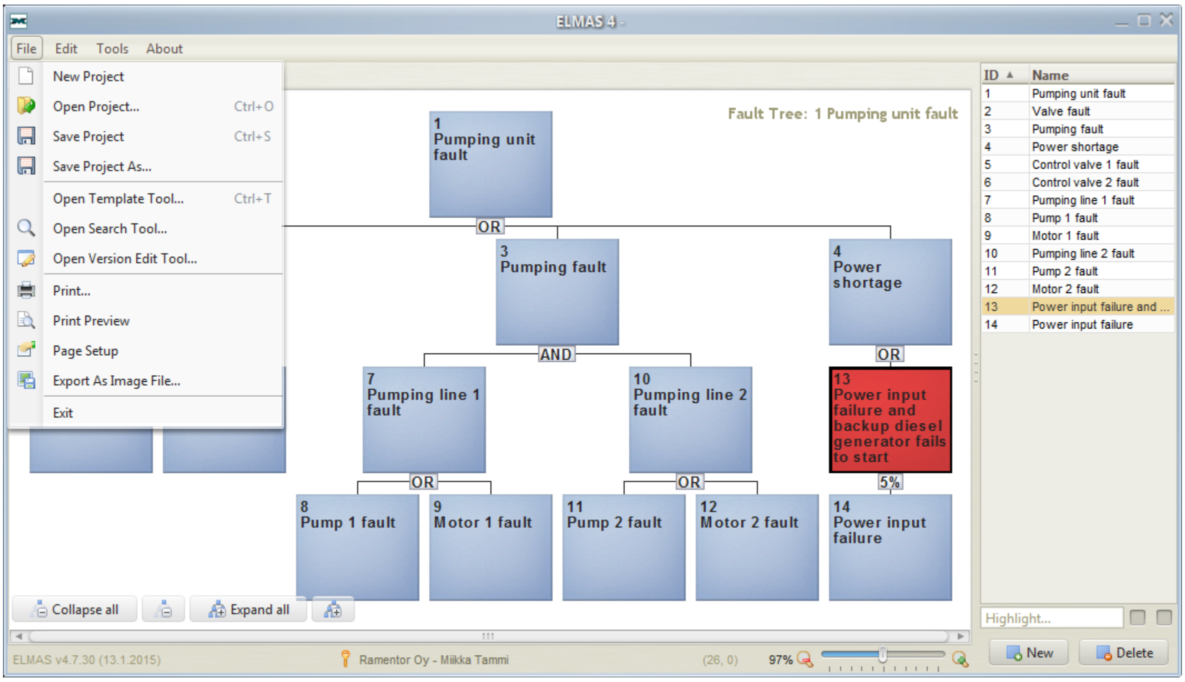
g) A Pumping line can handle all of the process flow so the Pumping fails only if both Pumping lines are at fault state. This is modeled by selecting AND as the logic rule.

h) After Power input failure the backup diesel generator is started. The 95 % probability to start can be modeled by adding a probability gate between the nodes 'Power shortage' and 'Power input failure'. A new gate is added by selecting *Add new gate as parent*.

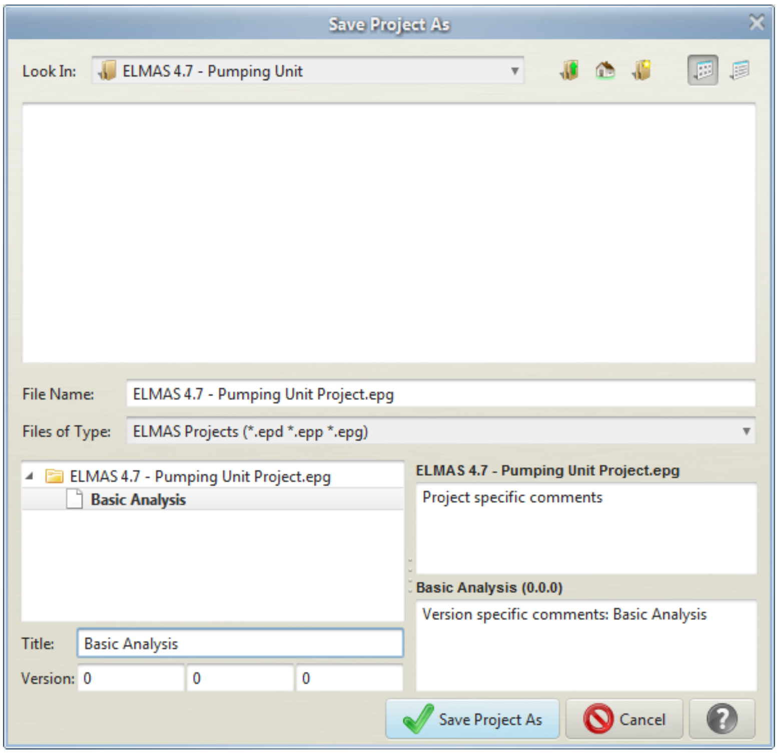


1.3 ELMAS – Save the Project with Version Management

i) It is good practice to save the created fault tree model regularly. It is possible to overwrite the currently open version (*File -> Save Project*) or use different project file, title or version (*File -> Save Project As…*).



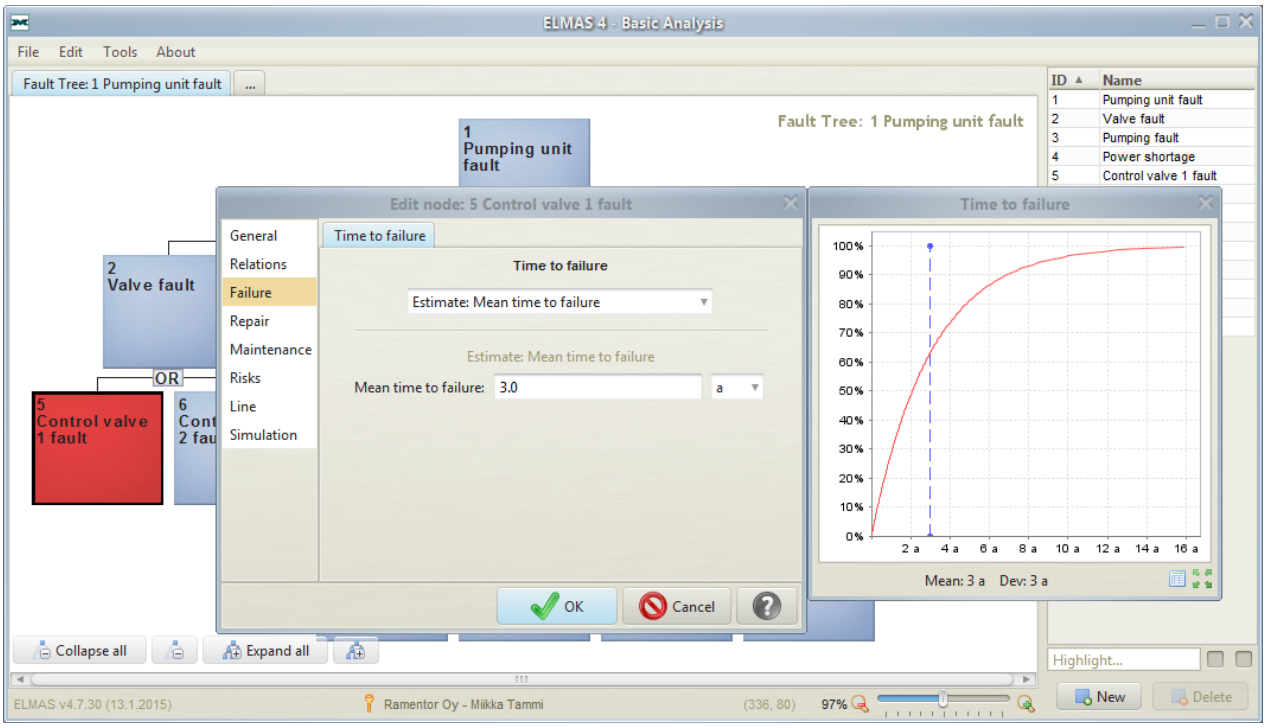
j) Several models can be saved inside a project file (.epg). For each model a title and three-level version numbering can be used. Information and notes relating to the project file and each separate version can be added by using the text fields shown at *Save As* dialog.



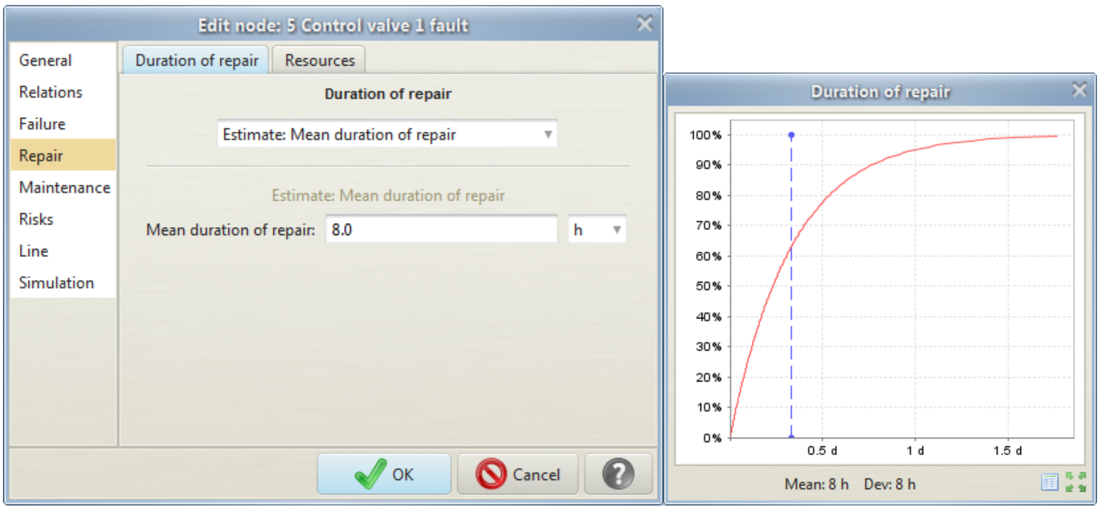
1.4 Fault Tree Analysis – Define Failure and Repair for Root Nodes

k) The behavior of each gate is defined by the child nodes and the logic of the gate. The behavior of each root is modelled separately by defining the failure and repair times. The definition is made at the *Failure* and *Repair* pages of the *Edit node* dialog.

l) There are several ways to define the failure time of a root depending on the available input data. The definition can be made based on history data or by directly estimating parameters related to the failure. The available methods shown in the *Time to failure* drop-down menu can be selected from *Options -> Tasks -> OK*. Method *Estimate: Mean time to failure*. The MTTF is defined and the failure distribution is created based on it.



m) Similarly with the failure definition there are several ways to define the repair time. With method *Estimate: Mean duration of repair* the MTTR is defined and the repair distribution is created based on it. In addition to the repair time from the *Resources* tab of the same page the needed personnel and direct repair costs can be defined.

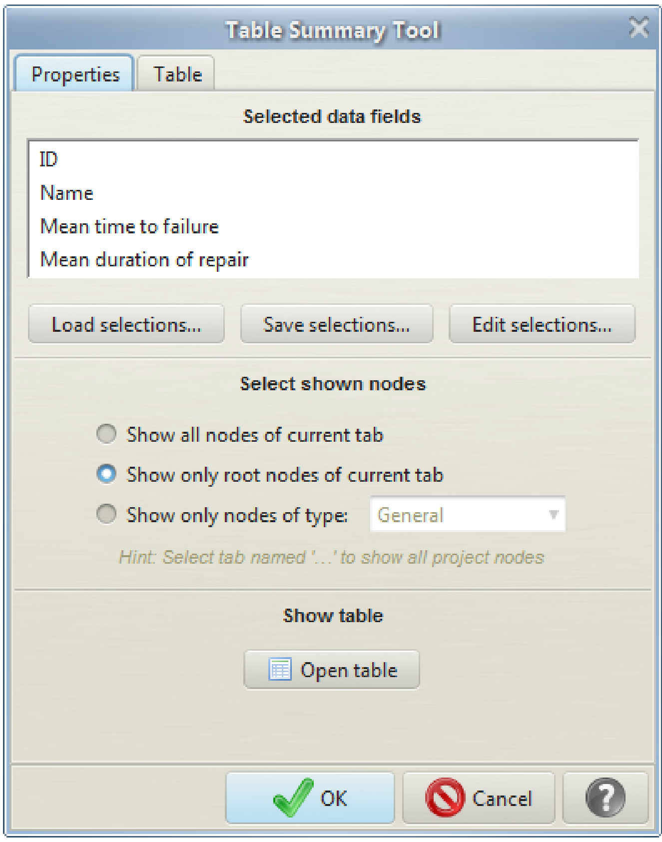


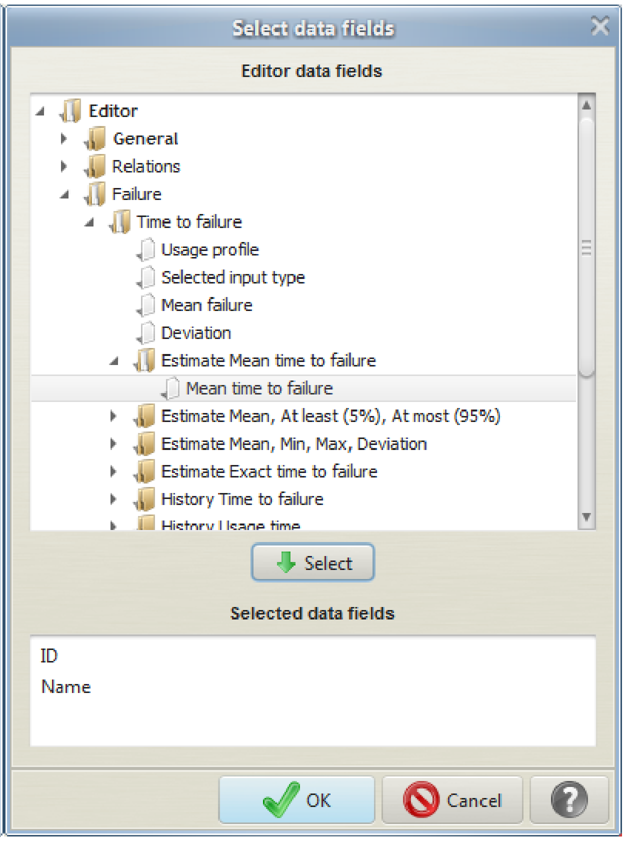
1.5 ELMAS – Table Summary Tool for Fast Data Edit

n) Table summary tool is opened by selecting *Tools -> Summary: Table* from the menu bar.

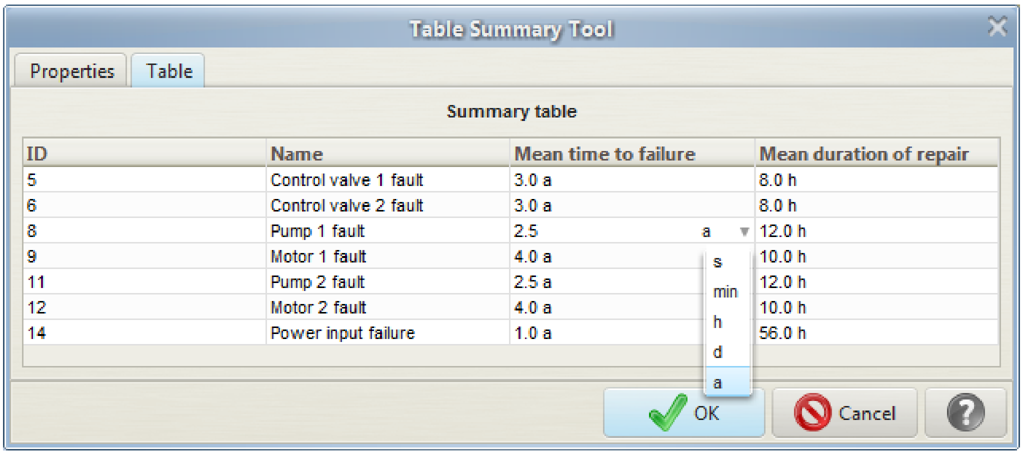
o) The shown data fields can be selected from the *Properties* tab by pressing *Edit selections*. Fields are included to the table by selecting them from the editor data fields tree (multiple selection with Ctrl) and pressing *Select*. The fields are deleted by selecting them again and pressing *Remove selection*.

p) For definition of failure and repair times only root nodes can be selected to be shown.





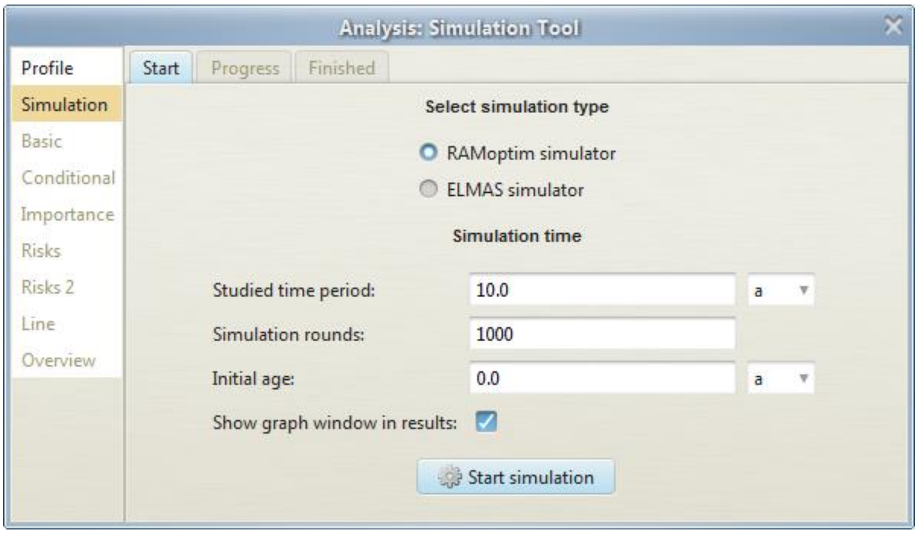
q) The *Table* tab shows the selected data fields of the selected nodes. Also copy-paste from for example Excel is possible. The edited changes are saved by pressing *OK*.



1.6 Fault Tree Analysis – Simulation

r) The Simulation Tool is launched by selecting *Tools -> Analysis: Simulation* from menu bar.

s) *Studied time period* (10 years) is simulated *Simulation rounds* (1000) times. After pressing *Start simulation* the simulation results pages will be soon available to show calculated result values and distributions.

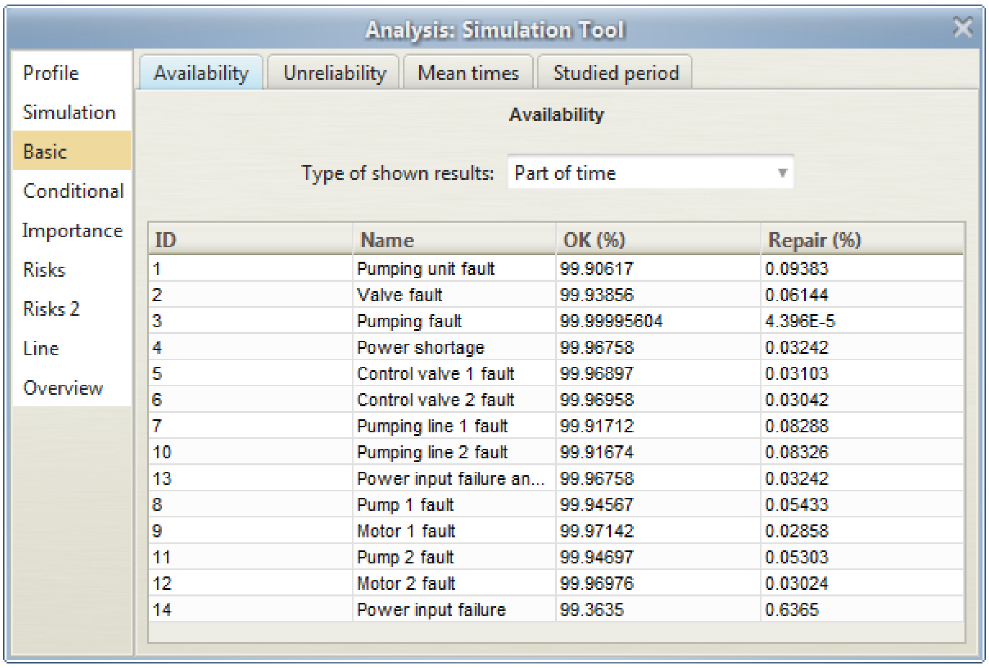


NOTE: Static seed 1424157511805 is used in this solution (*Tools->Options->Tools-> Random seed*)

1A) What is the availability of the pumping unit?

Answer for the first question can be found from page *Basic* and tab *Availability*.

Answer: Availability of the Pumping unit is 99.91 %.

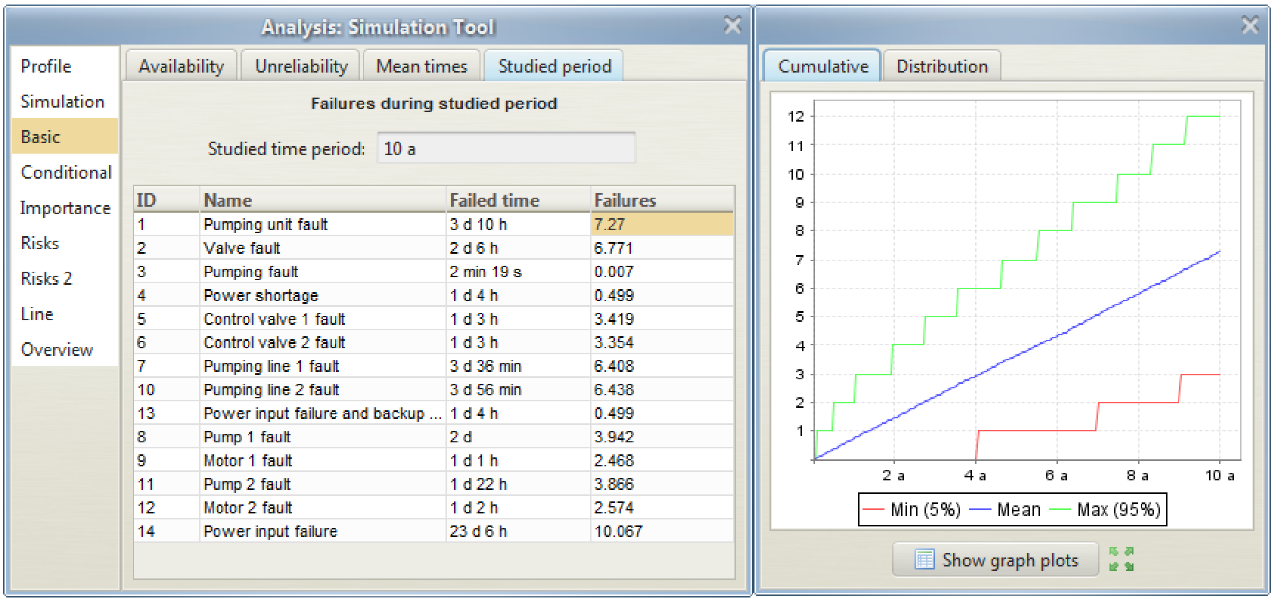


ID	Name	OK (%)	Repair (%)
1	Pumping unit fault	99.90617	0.09383
2	Valve fault	99.93856	0.06144
3	Pumping fault	99.99995604	4.396E-5
4	Power shortage	99.96758	0.03242
5	Control valve 1 fault	99.96897	0.03103
6	Control valve 2 fault	99.96958	0.03042
7	Pumping line 1 fault	99.91712	0.08288
10	Pumping line 2 fault	99.91674	0.08326
13	Power input failure an...	99.96758	0.03242
8	Pump 1 fault	99.94567	0.05433
9	Motor 1 fault	99.97142	0.02858
11	Pump 2 fault	99.94697	0.05303
12	Motor 2 fault	99.96976	0.03024
14	Power input failure	99.3635	0.6365

1B) How many failures will there occur during a 10-year period (mean and 90 % confidence)?

Answer for the question can be found from page *Basic* and tab *Studied period*.

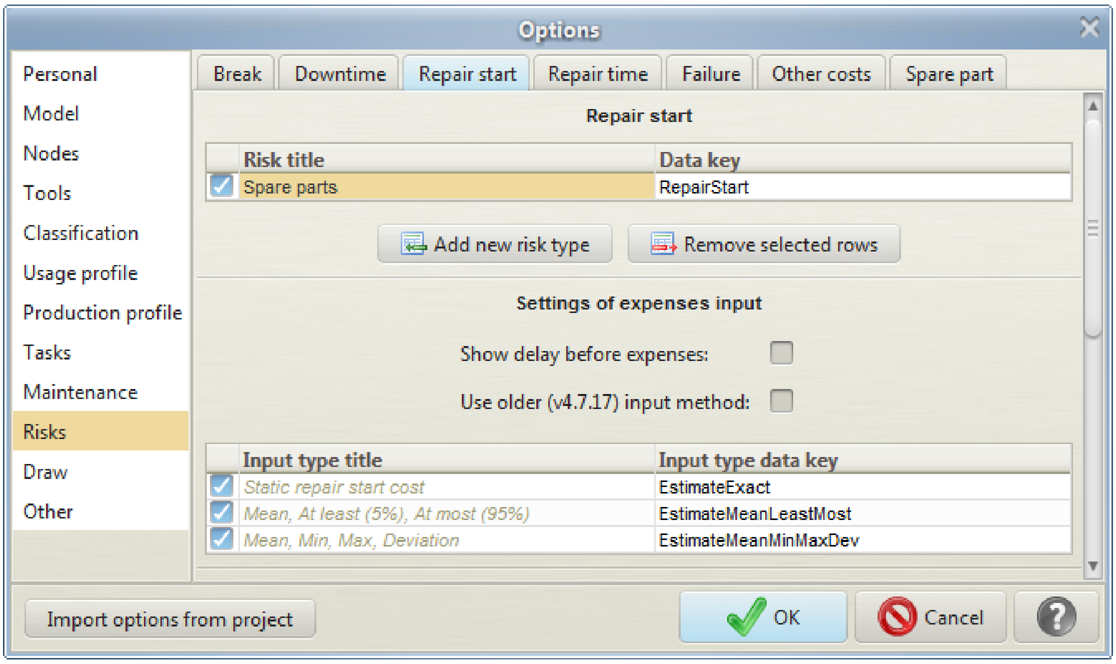
Answer: Mean number of failures is 7.27. With 90% confidence at least 3 and at most 12 failures.



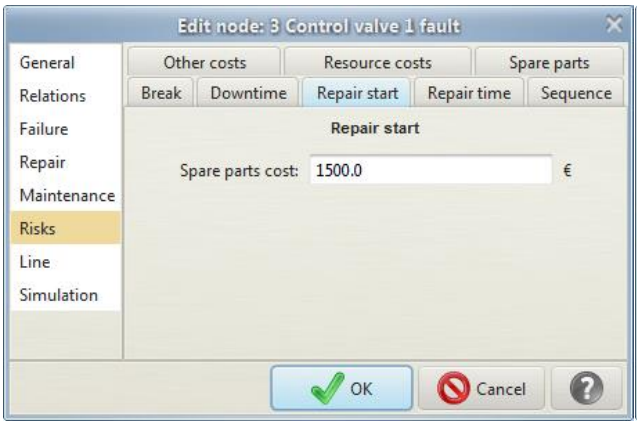
ID	Name	Failed time	Failures
1	Pumping unit fault	3 d 10 h	7.27
2	Valve fault	2 d 6 h	6.771
3	Pumping fault	2 min 19 s	0.007
4	Power shortage	1 d 4 h	0.499
5	Control valve 1 fault	1 d 3 h	3.419
6	Control valve 2 fault	1 d 3 h	3.354
7	Pumping line 1 fault	3 d 36 min	6.408
10	Pumping line 2 fault	3 d 56 min	6.438
13	Power input failure and backup ...	1 d 4 h	0.499
8	Pump 1 fault	2 d	3.942
9	Motor 1 fault	1 d 1 h	2.468
11	Pump 2 fault	1 d 22 h	3.866
12	Motor 2 fault	1 d 2 h	2.574
14	Power input failure	23 d 6 h	10.067

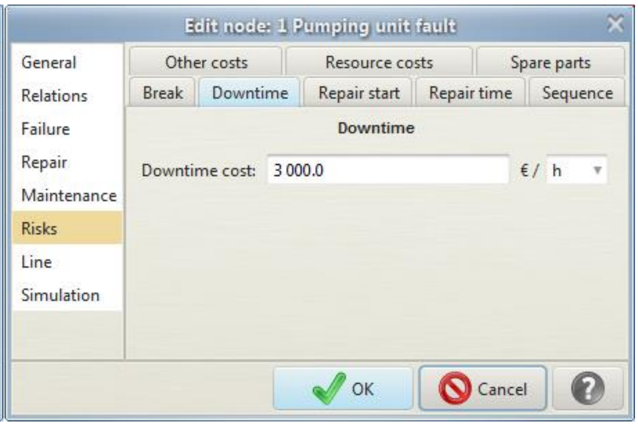
1.7 Fault Tree Analysis – Define Risks Data

t) Each risk data type has input fields which can be edited from *Tools* -> *Options* -> *Risks*. After editing press *OK* and select *Close all tools and change now*.



u) The costs that affect the risks can be added from *Risks* page. There are own tabs for different cost types.



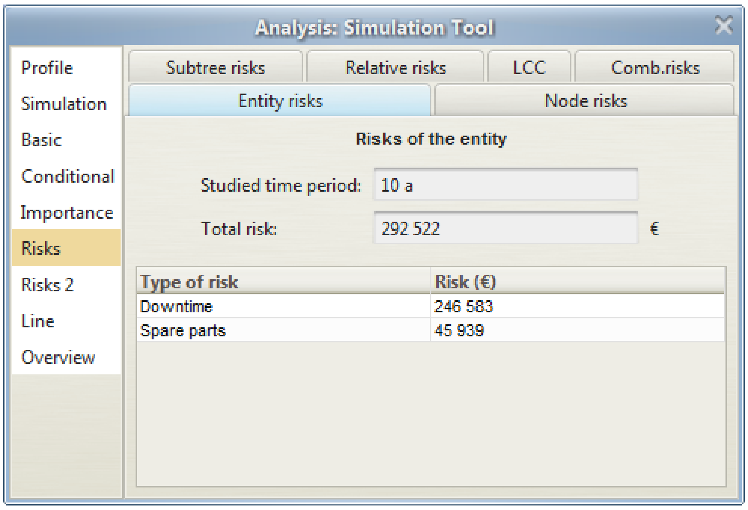


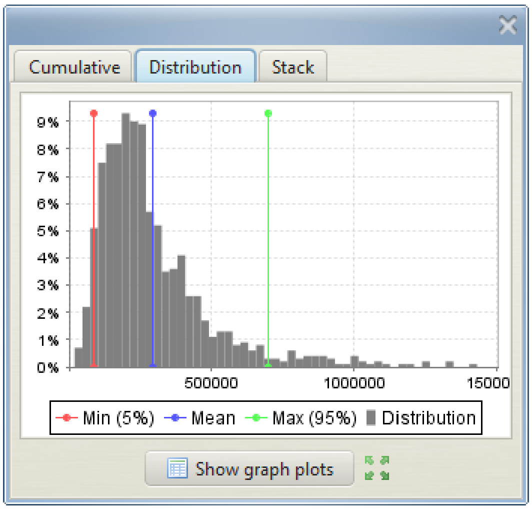
v) Risk data can also be added by using the table summary tool (*Tools -> Summary: Table*).

1C) What is the economic risk during a 10-year period when the costs are as follows?

Open the simulation tool and simulate again. Economic risks are shown at result tab *Risks*.

Answer: Economic risk caused by failures is 290 000 €.





NOTE: This result is the mean value of expected costs. Also much higher cost caused by failures is possible. With 95 % confidence the cost is less than 700 000 € and also cost over 1 000 000 € is possible. Similarly the real costs can be different than the expected mean value given in the following answers.

1.8 ELMAS – Save the Basic Analysis Version

w) Please remember to save the changes regularly. Because only improvements are made after chapter 1.3 the previous version can be overwritten. Select: *File -> Save Project*.

2 PUMPING UNIT SCENARIO ANALYSIS

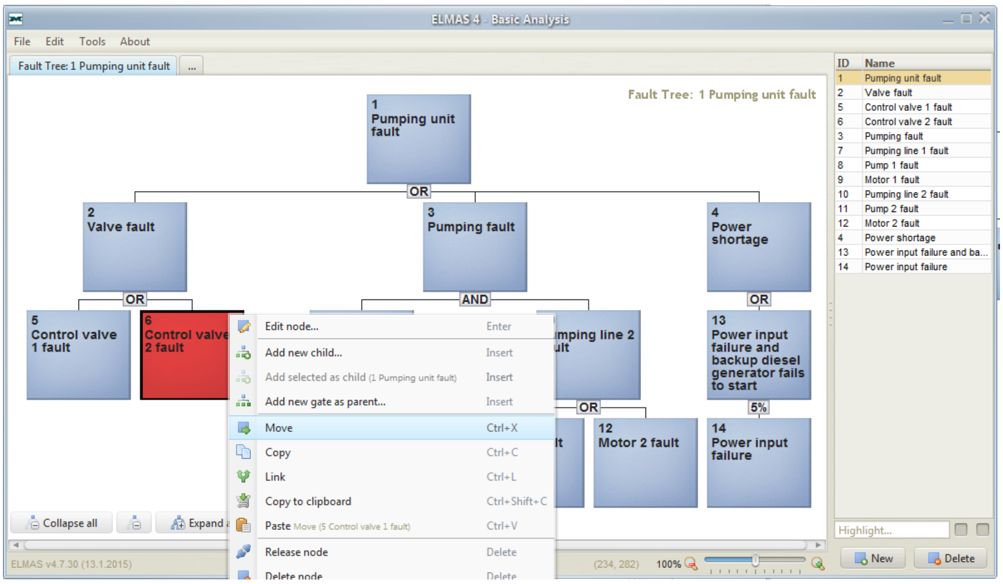
2.1 ELMAS – Drag and Drop, Move/Link/Copy and Paste, Delete

a) Scenario analysis requires changes to the model. There can be several ways to model the same scenario. One solution to model that a control valve can be replaced without shutting down the whole system is to move the Control valve fault nodes under the Pumping line fault nodes.

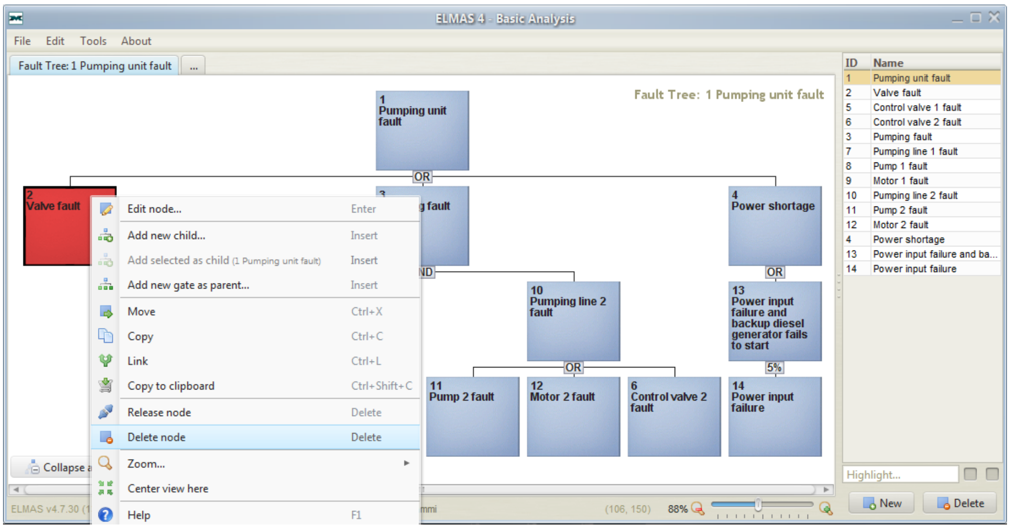
b) Move can be made with simple drag and drop by dragging a node to its new parent node.

c) If the dragging is made with *Shift* pressed, the node is linked to new location without removing it from the original location. If the dragging is made with *Ctrl* pressed, a copy of the dragged node is created to the new location.

d) *Move/Link/Copy* can be made also by selecting the operation by right-clicking a node. The operation is finished by right-clicking the destination node and selecting *Paste*.

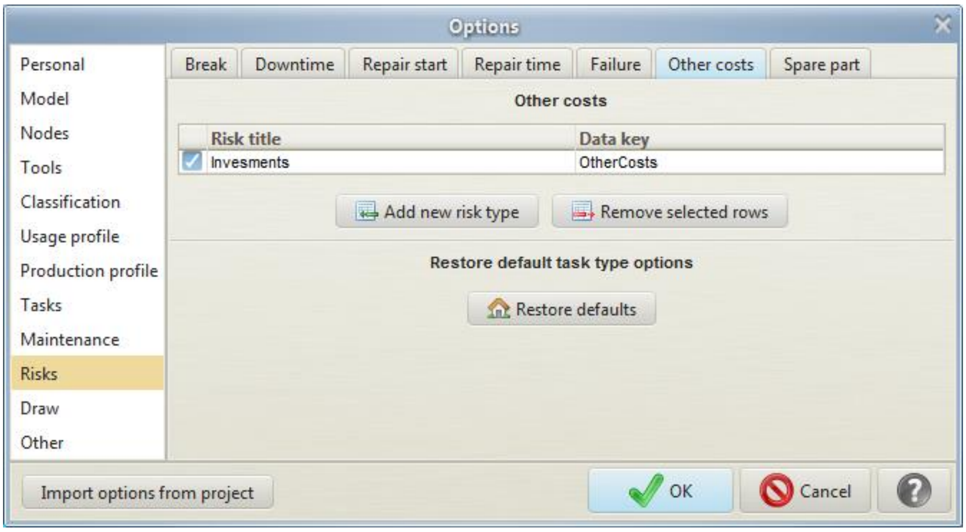


e) A node can be deleted by right-clicking the node and selecting *Delete node*.

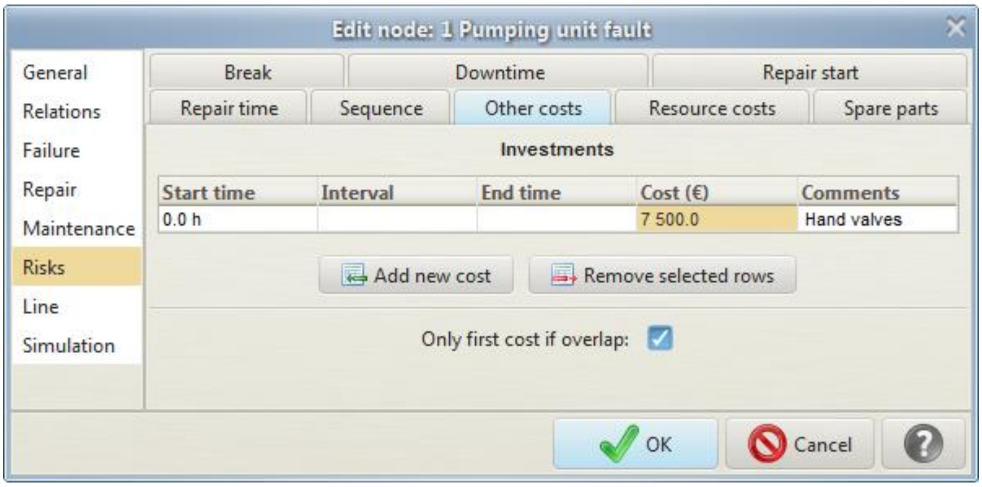


2.2 Fault Tree Analysis – Define Investment Costs

f) The input fields of risk data type *Other costs* can be edited from *Tools -> Options -> Risks*. You may replace *Investments* as the *Risk title* with a more suitable title that is used in *Edit node* dialog and simulation results. After editing press *OK* and select *Close all tools and change now*.



g) The investment costs are defined from *Other* costs tab of *Risks* page. The investment cost is made at the beginning so the start time should be 0. When an interval is not defined the cost is made only once.



2A) Would it be profitable to add hand valves before control valves?

New simulation reveals the economic risk of scenario 2A.

Answer: After the change the 10-year life-cycle costs (investment cost added by economic risk caused by failures) will be 135 000 e. The investment would be very profitable.

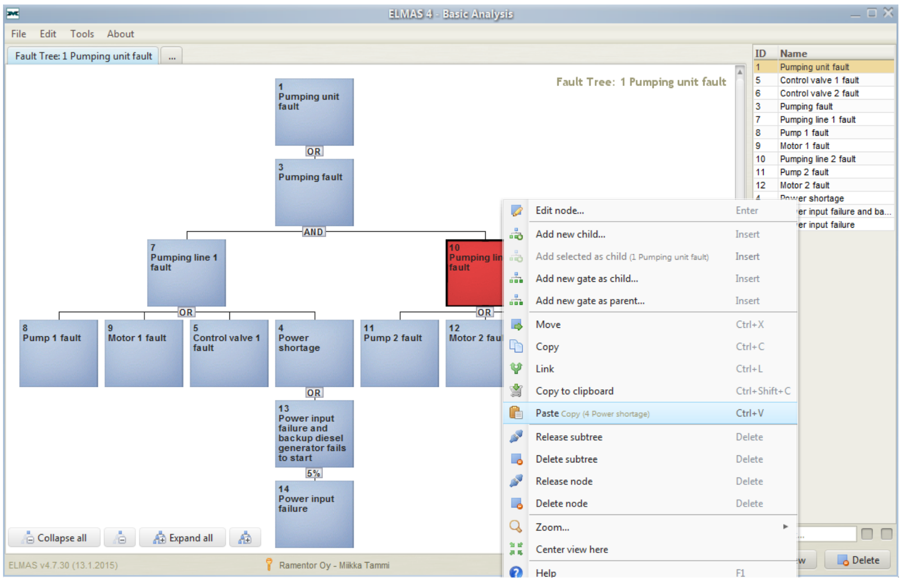
2.3 ELMAS – Save the Scenario 2A) Version

h) Select for example *File* -> *Save Project As* and give a new version title *Scenario 2A*.

2.4 Modification Steps – Scenario with Separate Power Inputs

i) Move the 'Power Shortage' subtree under one 'Pumping line' node (*Move* & *Paste*).

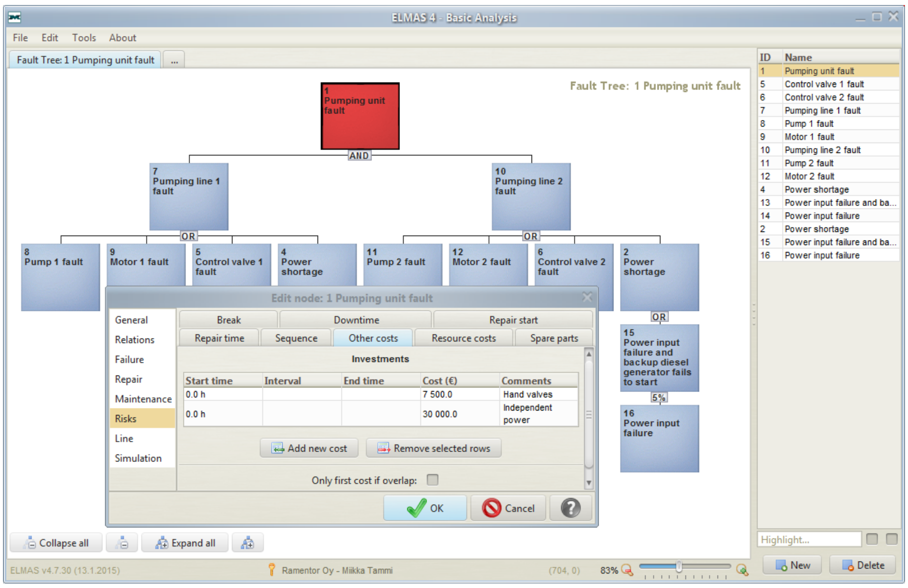
j) Take a copy of the 'Power Shortage' subtree and paste it under another 'Pumping line' node (*Copy* & *Paste*).



k) Delete the useless 'Pumping fault' node below the 'Pumping unit fault' (*Delete node*).

l) Change the gate type of 'Pumping unit fault' (*Edit node* -> *Relations* -> *Gate type*: AND).

m) Add 30 000 € investment cost to 'Pumping unit fault' node (*Edit node* -> *Risks* -> *Other costs*). NOTE: If you add two investment costs with exactly the same start time remember to uncheck the box 'Only first cost if overlap'.



2B) Would it also be profitable to create a separate power input for both pumping lines?

New simulation reveals the economic risk of scenario 2B.

Answer: After the change the 10-year life-cycle costs will be 85 000 €.

NOTE: With 95 % confidence the LCC will be less than 110 000 e, so not only the mean but also the risk of very large cost gets significantly lower.

2.5 ELMAS – Save the Scenario 2B) Version

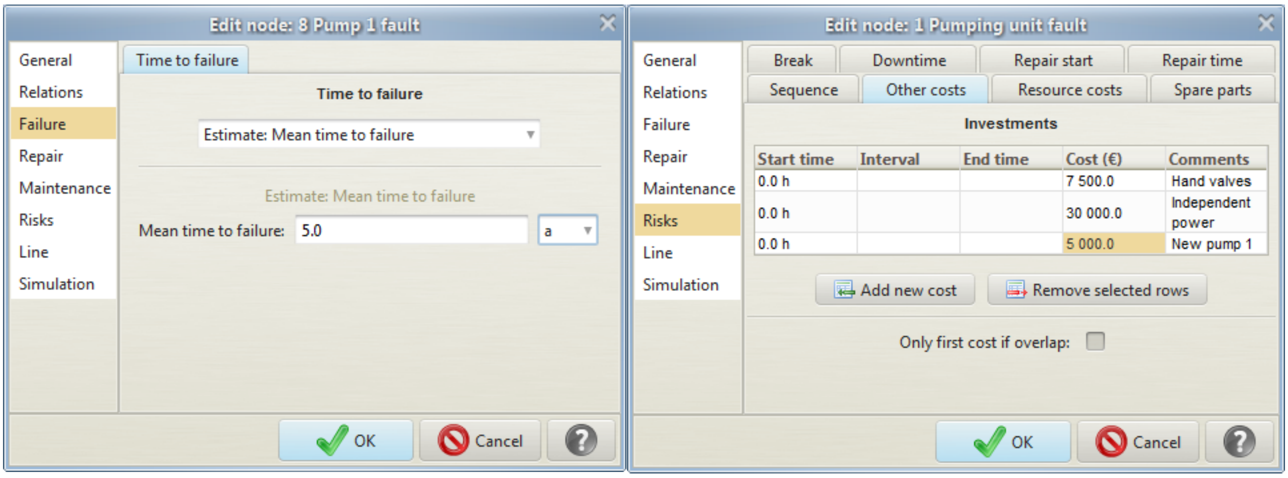
n) Select for example *File* -> *Save Project As* and give a new version title *Scenario 2B*.

2.6 Modification Steps – Scenario with a Better Pump

o) Update the failure time estimation of ‘Pump 1 fault’ node (*Edit node* -> *Failure*). The repair time estimation doesn’t change.

p) Update the spare part costs of ‘Pump 1 fault’ node (*Edit node* -> *Risks* -> *Repair start*).

q) Add 5 000 € investment cost to ‘Pumping unit fault’ node (*Edit node* -> *Risks* -> *Other costs*).



2C) Would it also be profitable to change the other pump for a better one?

New simulation reveals the economic risk of scenario 2C.

Answer: After the change the 10-year life-cycle costs will be over 90 000 €. Downtime costs are already so low that there isn’t enough saving potential to make this pump investment profitable.

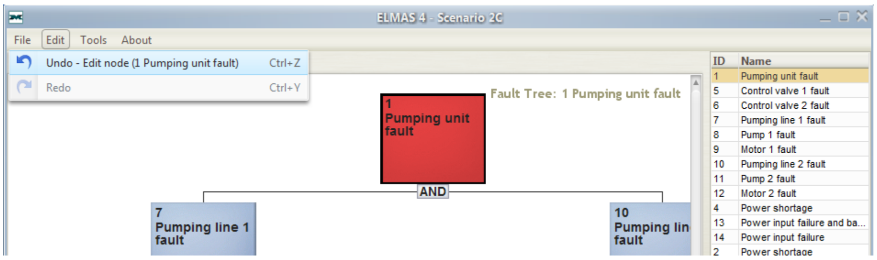
2.7 ELMAS – Save the Scenario 2C) Version

Select for example *File* -> *Save Project As* and give a new version title *Scenario 2C*.

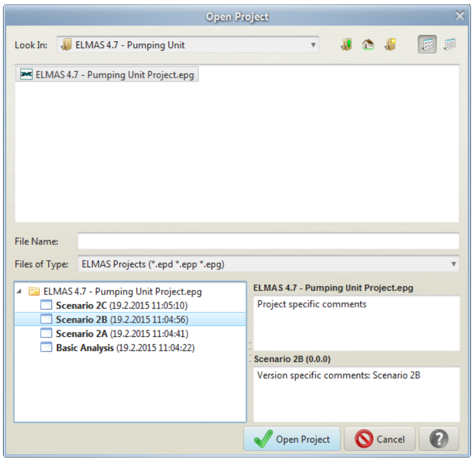
3 PUMPING UNIT ADVANCED ANALYSIS

3.1 ELMAS – Undo and Load Previous Version

a) It is possible to take back the undesired changes by selecting *Edit* -> *Undo*.



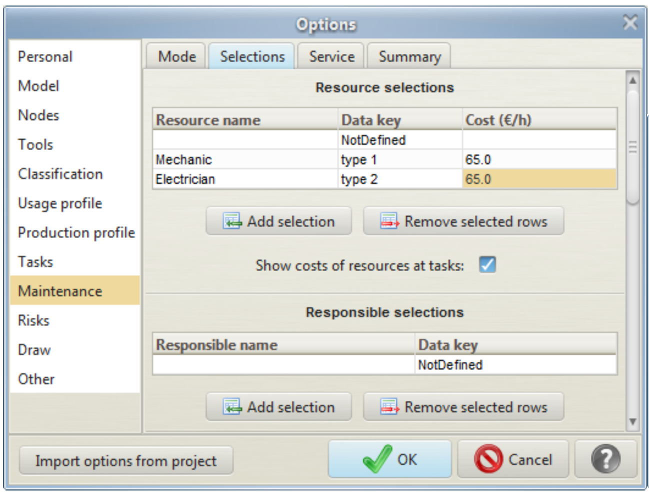
b) With regular saving and careful project versioning it is easy to open previous situations whenever needed. Saved project version can be opened from *Files* -> *Open project*.

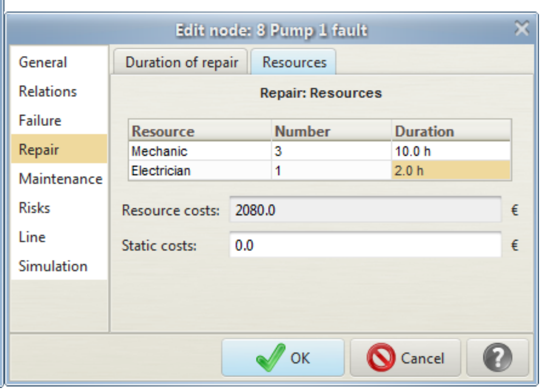


3.2 Fault Tree Analysis – Define Resource Groups and Maintenance Actions

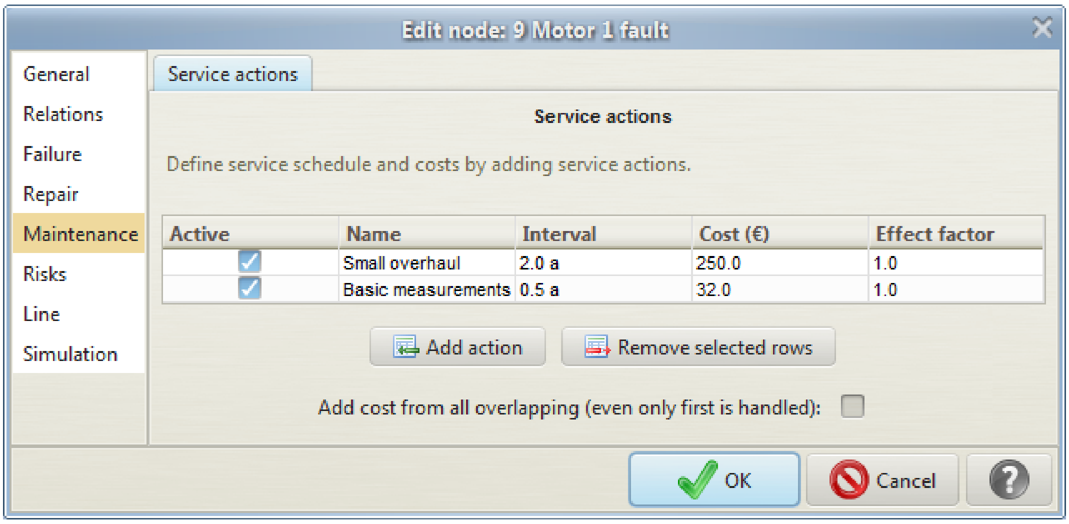
c) Define resource groups from: *Options* -> *Maintenance* -> *Selections* -> *Resource selection*.

d) The resource group specific costs are added from: *Node editor* -> *Repair* -> *Resources*





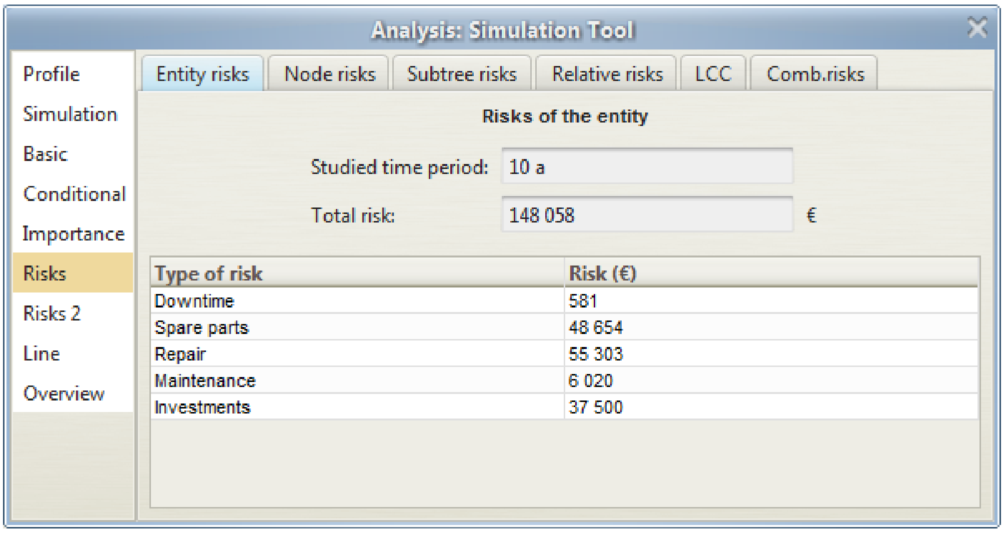
e) Maintenance actions can be added at *Node editor -> Maintenance*.



f) NOTE: *Effect factor* is used to define how the created maintenance action affects the failure behavior of the node. Value 1.0 means that the maintenance action has no effect. With a value of 0.5 the failure frequency of the part would become half of the original which means that the time between failures would double.

3A) What is 10 years LCC* with resource costs and maintenance actions included?

New simulation reveals the economic risk of scenario 3A.



Answer: With resources and maintenance actions included in the situation 2B) the Life-cycle cost (investment costs and total operation costs) will be 150 000 €.

3.3 ELMAS – Save the Scenario 3A) Version

Select for example *File -> Save Project As* and give a new version title *Scenario 3A*.

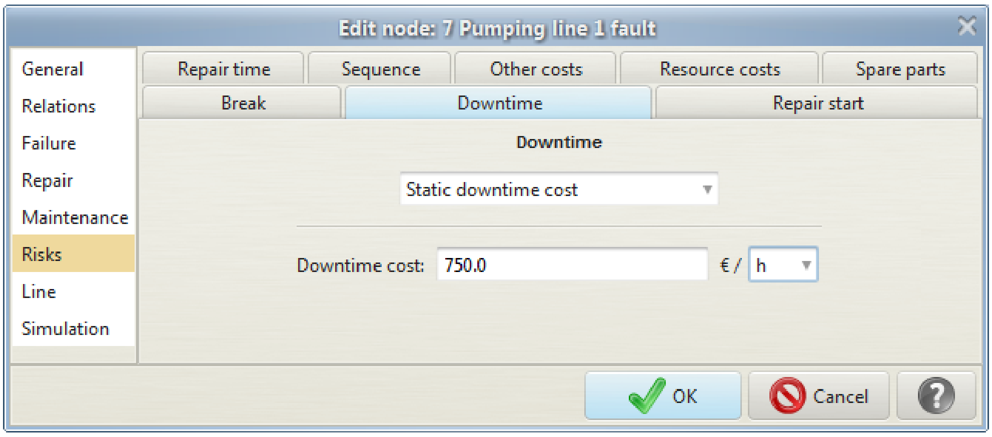
3.4 Fault Tree Analysis – Overlapping of Break and Downtime costs

g) The break and downtime costs are not cumulated in ELMAS if both the parent node and its child node are in a situation (failed) in which costs should be added. The costs of child nodes are ignored and only the cost of the parent node is added.

h) This behavior is useful only when the logic condition is other than OR. With OR gate the break and downtime cost should be added to only one tree level. If the cost is defined for an OR gate, the costs of the child nodes are never added because an OR gate always occurs when any of the child nodes are failed. The cost of an OR gate is overlapped with the costs of the child nodes and only the cost of an OR gate is added.

i) The repair start and repair time costs are handled in opposite way. They are always cumulated and never ignored because of overlapping.

j) By adding a downtime cost (750 €) to both 'Pumping line fault' nodes the 25% production loss can be modelled. Because of the overlapping behavior of ELMAS the changes are not needed to be made for the downtime loss of the Pumping unit fault node.



k) NOTE: Definition of delays of costs can be enabled from *Tools* -> *Options* -> *Risks*. With delays the overlapping property of downtime costs can be useful also with OR gates. (Delays of costs are not needed in this example)

l) NOTE: By default only static cost definition is used in ELMAS. Stochastic input methods can also be made available from *Tools* -> *Options* -> *Risks*. The available input types are selected separately for each cost type. (Other than static costs are not needed in this example)

3B) LCC if single pumping line is capable only for 75 % of the needed throughput?

New simulation reveals the economic risk of scenario 3B.

Answer: With the limitation of a single pumping line throughput the economic risk caused by production loss will get 190 000 € higher and the LCC will be 340 000 €.

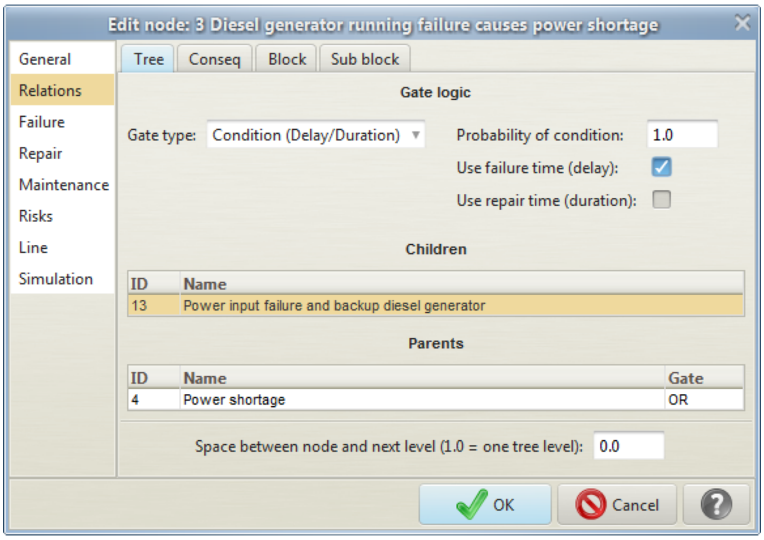
3.5 ELMAS – Save the Scenario 3B) Version

Select for example *File* -> *Save Project As* and give a new version title *Scenario 3B*.

3.6 Fault Tree Analysis – Condition, Delay, Duration and Probability Gates

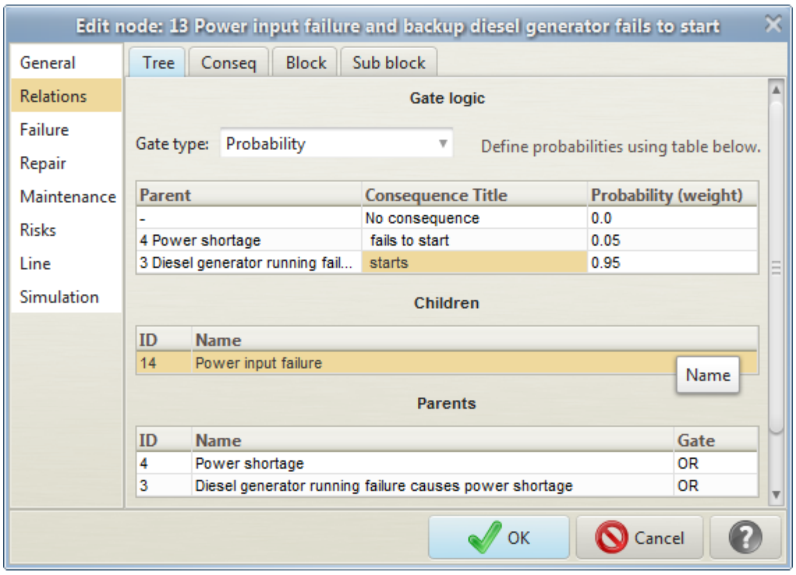
m) The condition gate can be selected from *Node editor* -> *Relations*. In basic situation it defines the probability rule between the child node and the gate. When the child node is failed the condition gate will be failed at a given probability.

n) Delay can be included in the condition gate by checking the *Use failure time (delay)*. A delay is defined in the *Failure* page similarly as with root node failure. When a child node is failed the gate will be failed after the defined delay.



o) Duration can be defined for the condition gate by checking *Use repair time (duration)*. The duration is defined in *Repair* page similarly with root node repair. When a gate node fails the duration of the failure of the child node does not affect the duration of the failure of the gate. (Repair gates are not needed in this example)

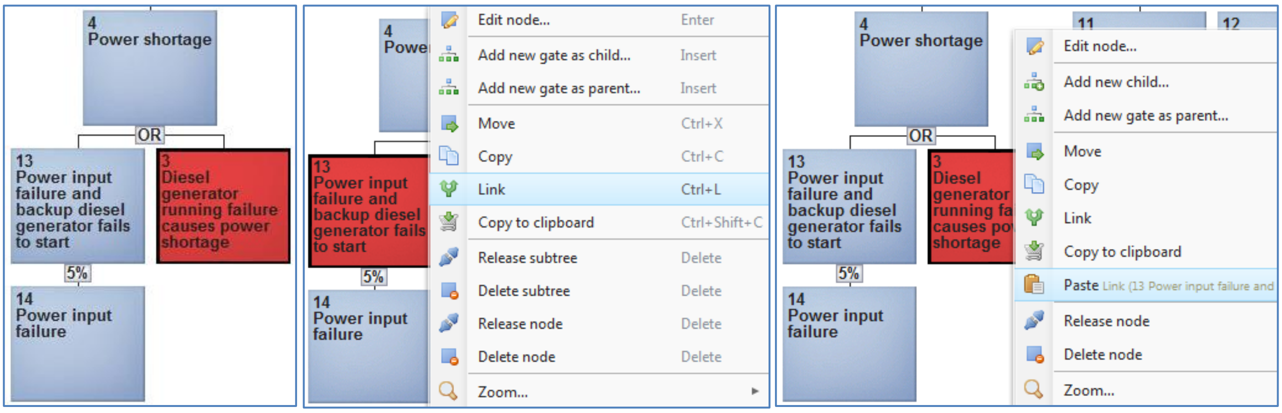
p) The probability gate is similar with condition gate that has only probability defined (no delay nor duration). The difference is that when a probability gate is linked under several nodes the probability can be defined for each of them separately. The linked consequences are exclusive. A probability gate is shown in the analysis results as many times as it has been linked.



3.7 Modification Steps – Scenario with Backup Generator Running Failures Considered

q) Add new node “Diesel generator running failure” (ID 3) under “Power shortage” node.

r) Use probability gate to separate event chains “Backup generator fails to start” and “Backup generator starts”.

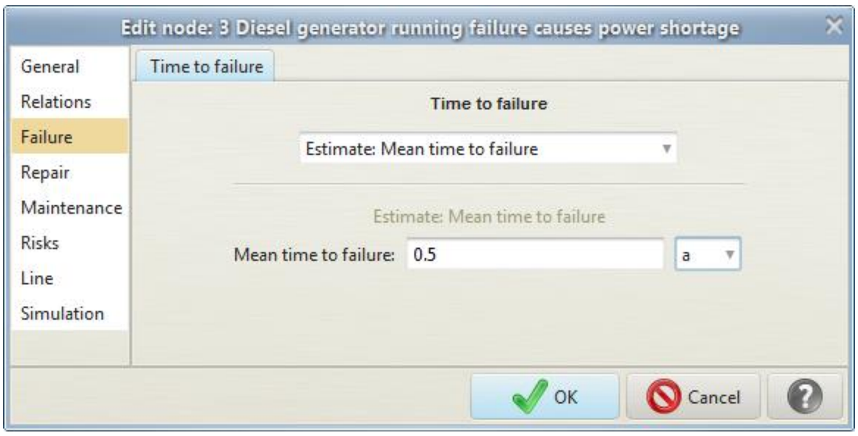


s) Rename the node “Power input failure and backup diesel generator fails to start” (ID 13) as “Power input failure and backup diesel generator”.

t) Define the node (ID 13) consequence titles and probability weights. For the parent “Power shortage” use *Consequence title* “fails to start” and probability 0.05. For the parent “Diesel generator running failure causes power shortage” use *Consequence title* “starts” and probability 0.95.

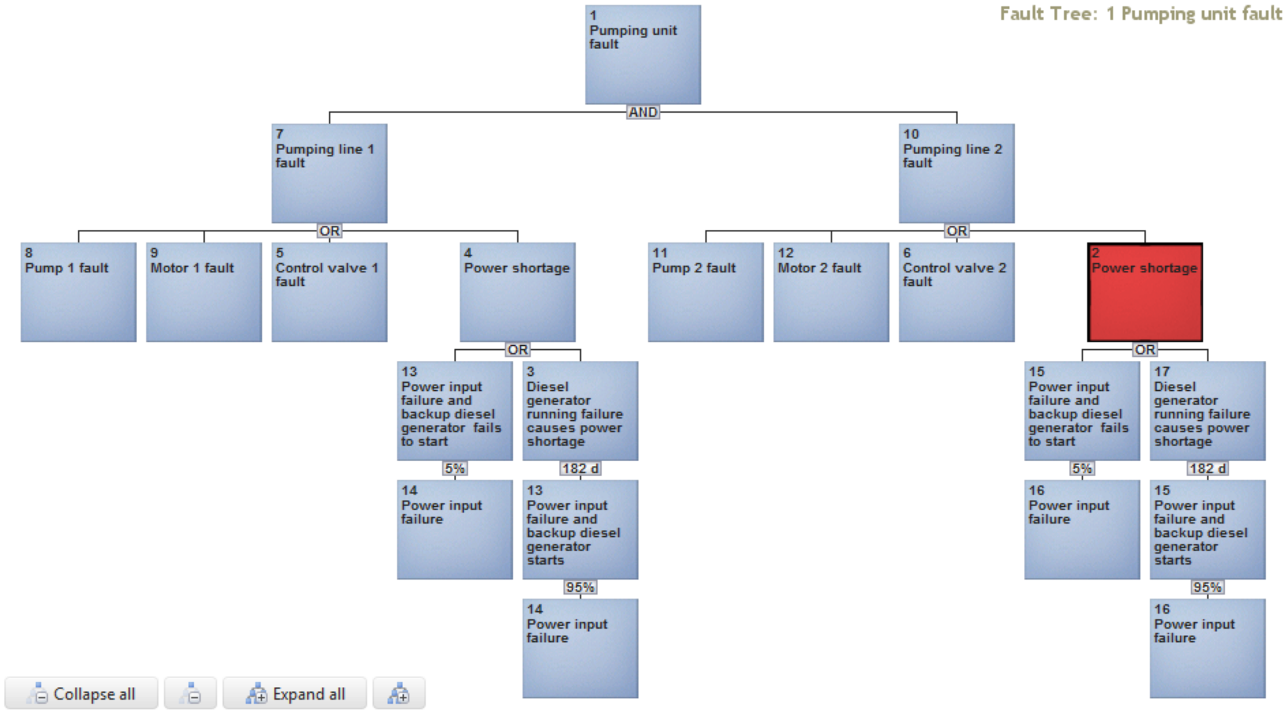
u) Use gate type *Condition (Delay/Duration)* to model “Diesel generator running failure causes power shortage” and select *Use failure time (delay)*.

v) Add MTTF estimation for backup diesel generator running failures.



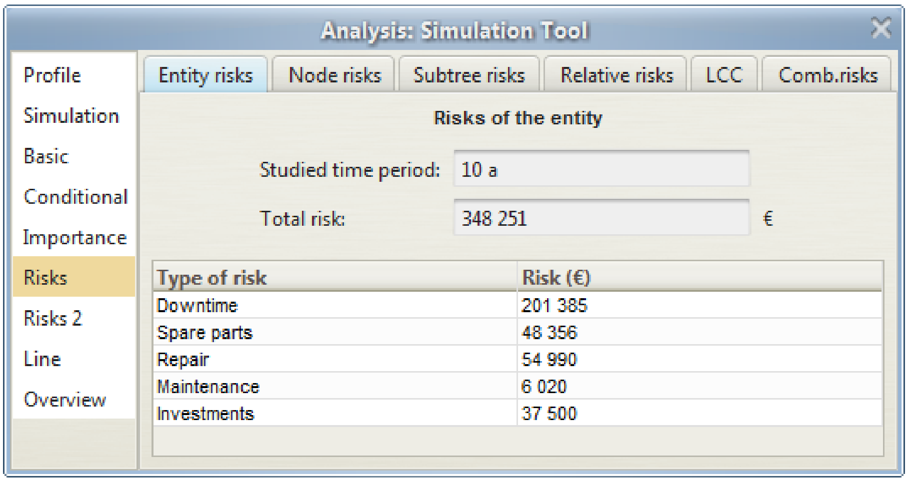
w) Set MTTR-field empty (no repair), because power input is repaired always.

x) Repeat the same steps to other Pumping line.



3C) Will the results change if backup generator failures after start are considered?

New simulation reveals the economic risk of scenario 3C.



Type of risk	Risk (€)
Downtime	201 385
Spare parts	48 356
Repair	54 990
Maintenance	6 020
Investments	37 500

Answer: Compared to situation 3B) the backup generators running failures cause 10 000 € extra economic risk. LCC of the pumping unit will be 350 000 €.

3.8 ELMAS – Save the Scenario 3C) Version

Select for example *File -> Save Project As* and give a new version title *Scenario 3C*.