

Ramentor Oy

ELMAS 4

Pumping Unit Example Solution

Version 1.0



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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 (<u>https://extranet.ramentor.com/elmas/</u>). 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.

*		ELMAS 4 -	_ = ×
File Edit Tools	About		las in
			ID Name
		Graph tab type	
		O Fault Tree	
		Cause Tree	
		Cause-Consequence Tree	
		Block Diagram	
		2-Level Process Diagram	
		Create new graph tab	
		Edit open graph tabs	
		There are no open graph tabs	
		Edit node: 1	
Gener	al	Edit node	
Relatio	ID:	1	-
Repair	Name:	Pumping unit fault	
	enance		
Risks	Description:		
Line			
Simul	ntion Node color:	Default	
	Notes:		
		Add attachment:	
		OK Scancel	
			Highlight
ELMAS v4.7.30 (13.1.2)15)	Ramentor Oy - Miikka Tammi 100% 🤤 👘	New Delete

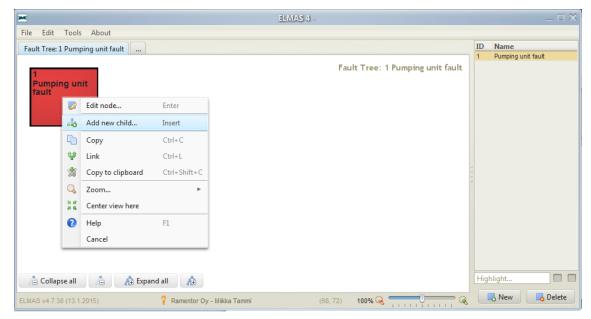
- c) Select Fault Tree graph tab type and press Create new graph tab.
- d) Define the studied system or event (*Pumping unit fault*) by using the fields (*ID*, *Name* and *Description*) of the opened *Edit node* dialog. You can also add notes, node color and attachments if needed. Press *OK* to save 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.



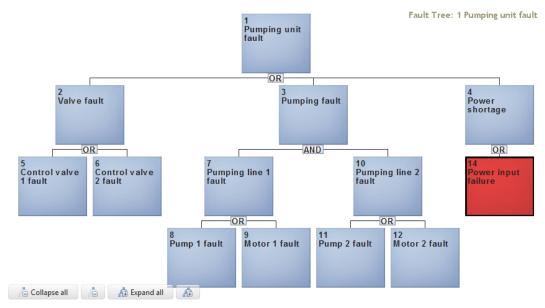
1 PUMPING UNIT BASIC ANALYSIS

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*.



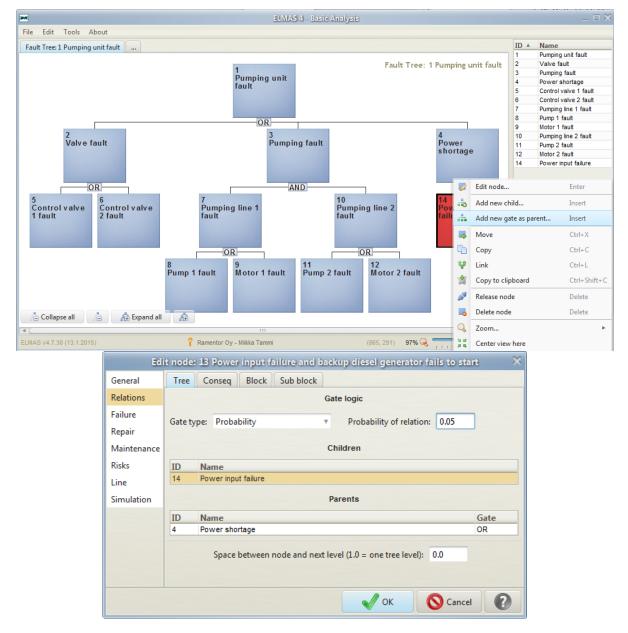
- c) Define the added cause by using the fields (*ID*, *Name* and *Description*) of the opened *Edit node* dialog. Press *OK* to save the edited data. The child node is added below the original.
- d) Continue building the fault tree model by repeating the previous steps until all the relevant causes are added to the model. The cause structure is now created.

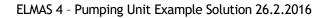




1.2 Fault Tree Analysis – Define Logic Conditions

- 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.

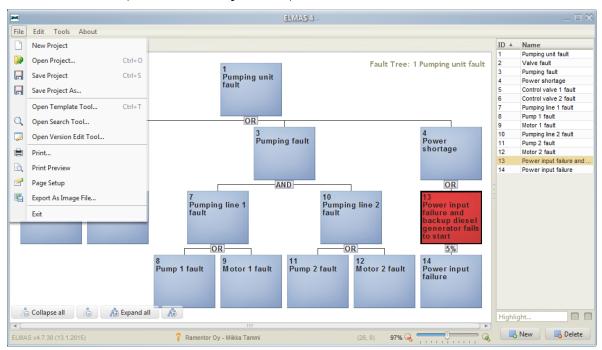




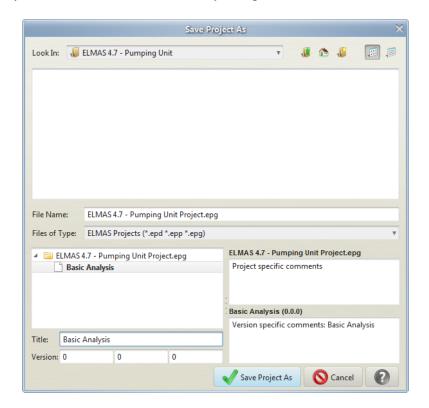


1.3 ELMAS – Save the Project with Version Management

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 threelevel 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.
- I) 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.

X	ELMAS 4 - Basic Anal	ysis		_ ¬ ×
File Edit Tools About				
Fault Tree: 1 Pumping unit fault	1 Pumping unit fault		lt Tree: 1 Pumping unit fault	ID A Name 1 Pumping unit fault 2 Valve fault 3 Pumping fault 4 Power shortage 5 Control valve 1 fault
	Edit node: 5 Control valve 1 fault	×	Time to fa	ilure 🛛 🗙
2 Valve fault Pailure Repair Maintenance Risks Control valve 1 fault Control valve Control valve Con	Time to failure Time to failure Estimate: Mean time to failure Estimate: Mean time to failure Mean time to failure: 3.0	v a v	100% 90% 80% 70% 60% 50% 40% 30% 2 a 4 a 6 a 8 a Mean: 3 a Dev: 3	
Collapse all	OK OC an	cel 🕐		
			4 (Highlight
ELMAS v4.7.30 (13.1.2015)	📍 Ramentor Oy - Miikka Tammi	(336, 80)	97% 🔍 💶 🖓	New Delete

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.

	Edit node: 5 Con	trol valve 1 fault	×	
General	Duration of repair Resour	rces		
Relations	(Ouration of repair		Duration of repair
Failure	Estimate: Mean	duration of repair	v	100%
Repair				90%
Maintenance	Estimate	: Mean duration of repair		80%
Risks	Mean duration of repair:	8.0	h v	70%
Line				60%
Simulation				50%
				40%
				30%
				20%
				10%
				0% 0.5 d 1 d 1.5 d
		🖌 🚫 Са	ncel	Mean: 8 h Dev: 8 h



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.

Table Summary Tool 🛛 🛛 🗙	Select data fields X
Properties Table	Editor data fields
Selected data fields ID Name Mean time to failure Mean duration of repair Load selections Save selections Edit selections Select shown nodes Show all nodes of current tab Show only root nodes of current tab Show only nodes of type: General Hint: Select tab named '' to show all project nodes Show table Open table Open table	Editor General Relations Failure Usage profile Selected input type Mean failure Deviation Estimate Mean time to failure Mean failure Estimate Mean, At least (5%), At most (95%) Estimate Mean, Min, Max, Deviation Estimate Exact time to failure History Time to failure History Time to failure Estimate Exact time to failure Estimate Exact time to failure Estimate Mean, Min, Max, Deviation Estimate Exact time to failure Estimate
OK 🚫 Cancel	OK 🚫 Cancel

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*.

Properties Tab	le				
	Su	mmary table			
ID	Name	Mean time to failure	Mean duration of repair		
5	Control valve 1 fault	3.0 a	8.0 h		
6	Control valve 2 fault	3.0 a	8.0 h		
8	Pump 1 fault	2.5 a	12.0 h		
9	Motor 1 fault	4.0 a s	10.0 h		
11	Pump 2 fault	2.5 a mi	12.0 h		
12	Motor 2 fault	4.0 a	10.0 h		
14	Power input failure	1.0 a h	56.0 h		
		d			
		a			



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.

			Analy	sis: Simulation Tool			×						
Profile	Start	Progress	Finished										
Simulation		Select simulation type											
Basic		RAMoptim simulator											
Conditional		ELMAS simulator											
Importance													
Risks				Simulation time									
Risks 2		Studied tir	me period:	10.0	a								
Line		Simulation	n rounds:	1000									
Overview		Initial age		0.0	a	*							
Show graph window in results:													
				🔅 Start simulation									

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 %.

		Ana	ilysis: Simu	lation Tool		· ·		
Profile	Availability Unreliability Mean times Studied period							
Simulation	Availability							
Basic		_						
Conditional	Type of shown results: Part of time							
Importance	ID	Nam	e	ОК (%)	Repair (%)			
Risks	1	Pump	ing unit fault	99.90617	0.09383			
Risks 2	2	Valve	e fault	99.93856	0.06144			
NISKS Z	3	Pump	ing fault	99.99995604	4.396E-5			
Line	4	Powe	r shortage	99.96758	0.03242			
Overview	5	Contr	ol valve 1 fault	99.96897	0.03103			
Overview	6	Contr	ol valve 2 fault	99.96958	0.03042			
	7	Pump	ing line 1 fault	99.91712	0.08288			
	10	Pump	ing line 2 fault	99.91674	0.08326			
	13	Powe	r input failure a	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	Powe	r input failure	99.3635	0.6365			



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

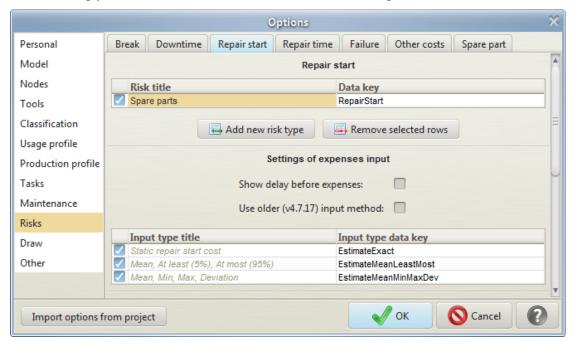
Answer for the question can be found from page *Basic* and tab *Studied period*.

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

		Analysis: Sin	nulation Tool		×							
Profile	Avail	ability Unreliability	Mean times St	udied period		Cun	nulative	Distrib	ution			
Simulation		Failures	s during studied p	eriod		12						
Basic	Studied time period: 10 a											
Conditional		studied time penou.	10 8			10						
Importance	ID	Name	Failed ti	ime Failu	ires	9						
	1	Pumping unit fault	3 d 10 h	7.27		8						
Risks	2	Valve fault	2 d 6 h	6.77	1							
Risks 2	3	Pumping fault	2 min 19	s 0.00	7	· ·						
	4	Power shortage	1 d 4 h	0.49	9	6						
Line	5	Control valve 1 fault	1 d 3 h	3.41	9	5				/		
Overview	6	Control valve 2 fault	1 d 3 h	3.35	4	4						
oremen	7	Pumping line 1 fault	3 d 36 m	in 6.408	3	3						
	10	Pumping line 2 fault	3 d 56 m	in 6.43	3	2		/				
	13	Power input failure and	backup 1 d 4 h	0.49	9	- 2						
	8	Pump 1 fault	2 d	3.943	2	1						
	9	Motor 1 fault	1 d 1 h	2.46	3							10
	11	Pump 2 fault	1 d 22 h	3.86	6		_	2 a	4 a	6 a	8 a	10
	12	Motor 2 fault	1 d 2 h	2.57	4			- Min (59	6) — Me	ean — Ma	x (95%)	
	14	Power input failure	23 d 6 h	10.00	67							
									Show gra	ph plots	15 JH 12 SH	

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.

	E	lit node: 3 Co	ontrol valve 1	fault		×		5	dit node	a 1 P	umping unit	fault			×
General	Other costs Resource costs			sts	Spare parts		General	Oth	er costs		Resource co	sts	Spa	are pa	arts
Relations	Break	Downtime	Repair start	Repair ti	me Sec	quence	Relations	Break	Downt	ime	Repair start	Repair tim	e	Seq	uence
Failure			Repair start			Failure	Downtime								
Repair	S	pare parts cost:	1500.0			€	Repair	Downti	me cost:	3 00	0.0		€.	/ h	Ŧ
Maintenance							Maintenance								
Risks							Risks								
Line							Line								
Simulation							Simulation								
		_			10	-				-				2	-
			🗸 ок	O c	ancel	0					√ ок	O Car	ncel		0

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 €.

	Analysis: Sin	nulation Tool		×	×
Profile	Subtree risks Rel	ative risks	LCC Co	mb.risks	Cumulative Distribution Stack
Simulation	Entity risks		Node risks		
Basic	Ri	sks of the entit	ty		9%
Conditional	Studied time period:	10 a			7%
Importance	Total risk:	292 522		€	5%
Risks	Total Hist.				4%
Risks 2	Type of risk	Risk (€)	1		3%
Line	Downtime Spare parts	246 583 45 939			2%
Overview					1% 0%
					500000 1000000 15000
					🔶 Min (5%) 🔷 Mean 🔷 Max (95%) 📕 Distribution
					Show graph plots

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 \in and also cost over 1 000 000 \in 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

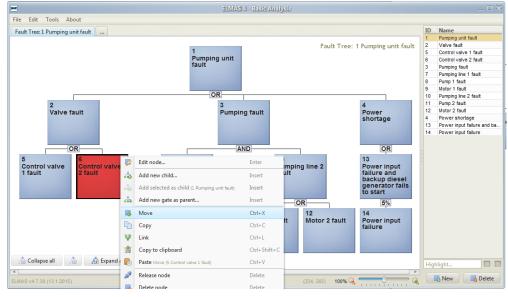
w) Please remember to save the changes regularly. Because only improvements are made after chapter 1.3 the previous version can be overwritten. Select: *File -> Save Project*.



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.

24				ELMAS 4 - Bas	ic Analysis				_ 🗆 ×
File Edit To	ools	About							
Fault Tree: 1 Pr	umpin	g unit fault						ID	Name
rout rectare	ampin	guntruut						1	Pumping unit fault
			4			Fault Tree: 11	umping unit fault	2	Valve fault
			Pumpin fault	a unit				5	Control valve 1 fault
			fault					6	Control valve 2 fault
								3	Pumping fault
					7	Pumping line 1 fault			
				20				8	Pump 1 fault
	_		3	DR				9	Motor 1 fault
2 Valve fault		Edit node		a fault			4 Power shortage	10	Pumping line 2 fault
Valve rutat	1	Edit hode	Enter	JICCIA			i onci snortuge	11	Pump 2 fault
	*	Add new child	Insert					12	Motor 2 fault
								13	Power shortage Power input failure and ba
	-	Add selected as child (1 Pumping unit fault)	Insert	10				14	Power input failure and ba
		Add new gate as parent	Insert	ND	10		OR 13		Tower input failure
		Move	Ctrl+X		10 Pumping line 2 fault		Power input failure and		
	G h	Сору	Ctrl+C				backup diesel generator fails		
	ψ	Link	Ctrl+L		0.0		to start		
	*	Copy to clipboard	Ctrl+Shift+C	11	OR 12	6	5%		
	339			Pump 2 fault	Motor 2 fault	Control valve 2	Power input		
	A	Release node	Delete			fault	failure		
	-	Delete node	Delete						
👌 Collapse a	Q	Zoom	Þ					Lie	hlight
4	3 B 2 B	Center view here		1			4 (
ELMAS v4.7.30 (1	0	Help	F1	mmi		06, 150) 88% 🔍 🗧	<u> </u>		New Delete



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.

			0	ptions				×
Personal	Break	Downtime	Repair start	Repair time	Failure	Other costs	Spare part	
Model				Other c	osts			
Nodes	Risk	title			Data key			
Tools	🗹 Inve	sments			OtherCost	3		
Classification			Add new r	isk type	Remov	e selected rows		
Usage profile								
Production profile			Res	tore default ta	sk type op	tions		
Tasks				Restore	defaults			
Maintenance								
Risks								
Draw								
Other								
Import options fr	om proje	ct				ОК	S Cancel	0

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.

General	Break		Downtime	Repair start		
Relations	Repair time	Sequence	Other costs	Resource costs	Spare parts	
Failure			Investment	8		
Repair	Start time	Interval	End time	Cost (€)	Comments	
Maintenance	0.0 h			7 500.0	Hand valves	
Risks		😽 Add new	cost 📃 📮 Re	move selected rows		
Line				-		
Simulation		Onl	y first cost if overla	ар: 🗹		
				Лок 🚫	Cancel	

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.

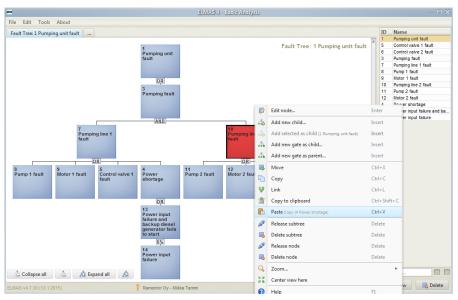


2.3 ELMAS – Save the Scenario 2A) Version

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'.

		ELMAS 4 - Basic Analysis	
Edit Tools	About		
ult Tree: 1 Pump	ing unit fault		ID Name
are received an array	ing and road		1 Pumping unit fault
		Fault Tree: 1 Pumping unit fault	5 Control valve 1 fault
		Pumping unit	6 Control valve 2 fault
		fault	7 Pumping line 1 fault
			8 Pump 1 fault
			9 Motor 1 fault
		AND	10 Pumping line 2 fault
	7	10	11 Pump 2 fault
	Pump	sing line 1 Pumping line 2	12 Motor 2 fault
	fault	fault	4 Power shortage
			13 Power input failure and 14 Power input failure
			2 Power shortage
		OR	15 Power input failure an
ump 1 fault	9 Motor 1 fault	5 4 11 12 6 2 Control valve 1 Power Pump 2 fault Motor 2 fault Control valve 2 Power	16 Power input failure
	General Relations	Edit node: 1 Pumping unit fault Break Downtime Repair start F Prepair time Sequence Other costs Resource costs Spare parts F F F F F F F F F F F F F	
	Failure	Investments backup diesel generator fails	
	Repair	Start time Interval End time Cost (€) Comments to start	
	Maintenance	0.0 h 7 500.0 Hand valves 5%	
	Risks	0.0 h 30 000.0 Independent power input	
	Line	failure	
	Simulation	Add new cost	
		Only first cost if overlap:	
		V OK Sancel	



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).

	Edit node: 8 Pump 1 fault 🛛 🗙		Ed	it node: 1 Pu	mping unit	fault	×
General	Time to failure	General	Break	Downtime	Repa	air start	Repair time
Relations	Time to failure	Relations	Sequence	Other cos	ts Reso	ource costs	Spare parts
Failure	Estimate: Mean time to failure	Failure			Investment	ts	
Repair		Repair	Start time	Interval	End time	Cost (€)	Comments
Maintenance	Estimate: Mean time to failure	Maintenance	0.0 h			7 500.0	Hand valves
Risks	Mean time to failure: 5.0	Risks	0.0 h			30 000.0	Independent power
Line		Line	0.0 h			5 000.0	New pump 1
Simulation		Simulation		Add new cos	t 📑 Re	emove selecte	ed rows
				Only fir	st cost if over	lap:	
	OK 🚫 Cancel				√ ок	0	Cancel

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 \in . 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*.

*			ELMAS 4 - Scenario 2C		_ = ×
File	Edit Tools About				
5	Undo - Edit node (1 Pumping unit fault)	Ctrl+Z		ID	Name
				1	Pumping unit fault
(Redo	Ctrl+Y	Fault Tree: 1 Pumping unit fault	5	Control valve 1 fault
			1	6	Control valve 2 fault
			Pumping unit	7	Pumping line 1 fault
			fault	8	Pump 1 fault
				9	Motor 1 fault
				10	Pumping line 2 fault
				11	Pump 2 fault
			AND	12	Motor 2 fault
	7		10	4	Power shortage
	Pumping line 1		Pumping lin	13	Power input failure and ba
	fault		fault	14	Power input failure
				2	Power shortage

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*.

Open P	rojest ×
Look In: 🕠 ELMAS 4.7 - Pumping Unit	· 🦛 💩 👘 🔎
ELMAS 4.7 - Pumping Unit Project.epg	
File Name:	
Files of Type: ELMAS Projects (*.epd *.epp *.epg)	Ŧ
Genario 2C (19.2015 11:05:0) Genario 2C (19.2015 11:05:0) Genario 2C (19.2015 11:05:0) Genario 2A (19.22015 11:04:65) Scenario 2A (19.22015 11:04:61) Back Analysis (19.22015 11:04:22)	ELMAS 4.7 - Pumping Unit Project.epg Project specific comments Scenario 28 (0.0.0) Version specific comments: Scenario 28
	V Open Project O Cancel

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

	Opt	ions		×					
Personal	Mode Selections Se	vice Summary							
Model	R	esource selection	s	A					
Nodes	Resource name	Data key	Cost (€/h)						×
Tools		NotDefined		=		Edit no	ode: 8 Pump 1 fa	ult	~
a	Mechanic	type 1	65.0		General	Duration of repa	air Resources		
Classification	Electrician	type 2	65.0		Relations				
Usage profile				4	Relations		Repair: Reso	urces	
Production profile	🐱 Add selectio	n 📑 Remov	ve selected rows		Failure	Resource	Number	Duration	
Tasks	Chour costs	of resources at tas	ikan 🔽		Repair	Mechanic	3	10.0 h	
	Show costs	or resources at tas	KSi 🔽		Maintenance	Electrician	1	2.0 h	
Maintenance					D: 1				_
Risks	Res	sponsible selectio	ns		Risks	Resource costs:	2080.0		€
Draw	Responsible name		a key		Line	Static costs:	0.0		€
Other		NotD	efined		Simulation				
	Add selectio	n 📑 Remov	ve selected rows	Ŧ					
Import options f	rom project	√ ок	Cancel	0			√ ок	S Cancel	0



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

		Edit node:	9 Motor 1 fa	ult	3
General	Service actions				
Relations			Service acti	ons	
Failure	Define service sch	nedule and costs by ad	ding service ad	tions.	
Repair			-		
Maintenance	Active	Name	Interval	Cost (€)	Effect factor
Risks		Small overhaul	2.0 a	250.0	1.0
		Basic measurements	0.5 a	32.0	1.0
Line Simulation		Add action	n 📑 Re	move selected rows	
		Add cost from all over	lapping (even	only first is handled):	
				🗸 ок 🛛 🕻	S Cancel

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.

	Analysis: Simulation Tool 🛛 🕹								
Profile	Entity risks	Node risks	Subtree ris	ks	Relative risks	LCC	Comb.ris	cs	
Simulation			Ri	sks	of the entity				
Basic		Studied ti	ime period:	10 a	1				
Conditional		Total risk		148	050	€			
Importance		TOTALLISK		140	000		e		
Risks	Type of risk				Risk (€)				
Risks 2	Downtime				581				
	Spare parts				48 654				
Line	Repair				55 303				
Overview	Maintenance				6 020				
	Investments				37 500				

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.

		Edit node	: 7 Pumping line 1	fault		×
General	Repair time	Sequence	Other costs	Resource	costs	Spare parts
Relations	Break		Downtime		Repair	start
Failure			Downtime			
Repair		Sta	tic downtime cost			
Maintenance						
Risks		Downtime cost:	750.0	€	/ h =	
Line					· []	
Simulation						
				√ ок	O C	ancel

- 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)
- 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.

3	dit node	: 3 Diese	l genera	tor running	y fail	ure causes power shortag	je	×
General	Tree	Conseq	Block	Sub block				
Relations				(Gate Id	ogic		
Failure	Gate typ	e Condi	tion (Dela	y/Duration)	-	Probability of condition:	1.0	
Repair	outetyp	condi	cion (Deci	iy, o diadony		Use failure time (delay):		
Maintenance							-	
Risks						Use repair time (duration):	-	
Line					Child	ren		
Simulation	ID	Name						
	13	Power inpu	t failure ar	nd backup dies	sel ger	erator		
					Pare	nts		
	ID	Name					Gate	
	4	Power sho	rtage				OR	
		Space be	tween no	de and next	level (1.0 = one tree level): 0.0		
						V OK Or Cano	el 🕜	

- 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.

General	Tree	Conseq	Block	Sub block				
Relations				Gate lo	ogic			
Failure	Catal	Deskah	10a	v				
Repair	Gate t	ype: Probab	onity	*	Define proba	bilities using	table below.	
Maintenance	Pare	nt		Consequenc	e Title	Probability	(weight)	
Risks			No consequence		0.0			
KISKS	4 Power shortage		fails to start		0.05			
Line	3 Diesel generator running fail		starts		0.95			
Simulation				Childr	en			
	ID	Name						
	14		Name					
				Paren	its			
	ID Name						Gate	
							OR	
	4	Power shore	age					



3.7 Modification Steps – Scenario with Backup Generator Running Failures Considered

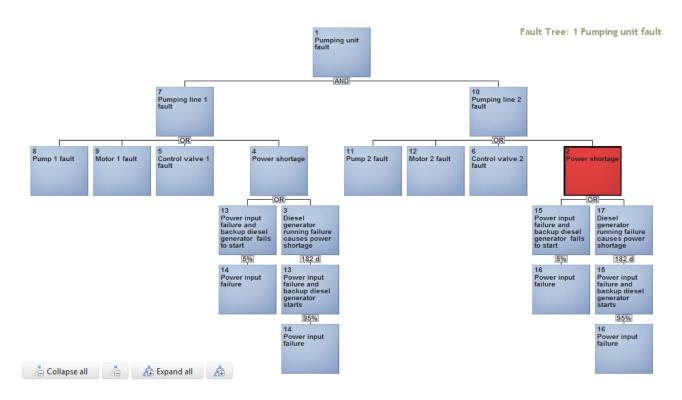
- q) Add new node "Diesel generator running failure" (ID 3) under "Power shortage" node.
- r) Use probability gate to separate event chains "Backup generator fails to start" and "Backup generator starts".

4	4	Ø	Edit node	Enter	4		11 12
Power shortage	Powe	-	Add new gate as child	Insert	Power shortage		Edit node
		*	Add new gate as parent	Insert		-	Add new child
OR		-	Move	Ctrl+X	OR	-	Add new gate as parent
13 3	13	D	Сору	Ctrl+C	13 3		Move
Power input Diesel generator	Power input failure and	Ψ	Link	Ctrl+L	Power input Diesel generato	•	Сору
backup diesel running failure generator fails causes power	backup diesel generator fails	\$	Copy to clipboard	Ctrl+Shift+C	backup diesel running f generator fails causes po		Link
to start shortage	to start		Release subtree	Delete	to start shortage	\$	Copy to clipboard
5%	<u>5%</u>	-	Delete subtree	Delete	5%	ß	Paste Link (13 Power input failure and
Power input failure	Power input failure	S	Release node	Delete	Power input failure	<i>"</i>	Release node
		-	Delete node	Delete		-	Delete node
		Q	Zoom	٠		Q	Zoom

- 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.

B	dit node: 3 Diese	l generator r	unning failure cau	ises power	shortage	×
General	Time to failure					
Relations			Time to failure			
Failure		Estimate: Me	an time to failure		v	
Repair						
Maintenance		Esti	mate: Mean time to I	failure		
Risks	Mean	time to failure:	0.5		a 🔻	
Line						
Simulation						
				ок 🤇	Cancel	0

- 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.

Profile	Entity risks Node risks Subt	tree risks Relative risks	LCC Comb.risks					
Simulation	Risks of the entity							
Basic	Studied time period:	10 a						
Conditional		240.054						
Importance	Total risk:	348 251	€					
Risks	Type of risk	Risk (€)						
Risks 2	Downtime	201 385						
NISKS Z	Spare parts	48 356	48 356					
Line	Repair	54 990	54 990					
Overview	Maintenance	6 020						
Overview	Investments	37 500	37 500					

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

3.8 ELMAS – Save the Scenario 3C) Version

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