Formulas

SILcet 4.0

Enertria

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SILcet

Silcet 4.0 – Extract of used formulas

Index

Links to the website: English or Spanish

1 List of abbreviations

PFD	Probability of Failure on Demand	STR	Spurious Trip Rate
PFD_{avg}	The Average Probability of Failure on Demand	MTBF	Mean Time between Failures
PFH	Probability of Dangerous Failure per Hour	MTTF	Mean Time to Failure
Cpt	Proof Test Coverage	MTTFS	Mean Time to Fail Spurious
TI	Test Interval (periodic tests)	MTTR	Mean Time to Repair
LT	Life Time of the SIF	$MTTR_s$	Mean Time to Repair a Safe failure
λ_{DU}	Rate of Dangerous Undetected failures	PFS	Probability of Failure Spurious
λ_{DD}	Rate of Dangerous Detected failures	MooN	Architecture M out of N
λ_{SU}	Rate of Safe Undetected failures	PST	Process Safety Time
λ_{SD}	Rate of Safe Detected failures		
β	Beta factor for common cause failures		
CC	Common Cause		
PTD	Proof Test Duration (hours with bypass activated)		
DC	Diagnostic Coverage		
SFF	Safe Failure Fraction		
SIF	Safety Instrumented Function		
SIL	Safety Integrity Level	IEC	International Electrotechnical Commission
SIS	Safety Instrumented System	FMEA	Failure Mode and Effect Analysis
HFT	Hardware Fault Tolerance	FMEDA	Failure Modes, Effects, and Diagnostic Analysis
FIT	Failures in Time (failures per billion hours; λ=FIT x 1E-9)	PL	Performance Level

2 Introduction

This document contains a **summary of the equations and calculation methods** used in the tool **SILcet** (SIL Calculation Excel Tool).

The following calculation options are included:

1-For PFDavg (low demand):

-Sheets “SIL” & “SIL2”: For calculations based on extended simplified equations (most based on IEC-61508 & ISA TR84).

It’s the recommended option for most SIFs. Architectures: 1oo1, 1oo2, 2oo2, 2oo3, 2oo4, 1oo2D, 1oo3, 1oo4, 1oo5, 3oo3, 4oo4, 2oo5, 1oo2R, 2oo2S, Kx1oo2, 3oo4, 3oo5, 4oo5, 1ooM, and 1oo2div, 2oo2div on sheet “SIL”.

-Sheet “CF”: For calculations based on integrals and later averaging over the periods TI and LT. It’s recommended only for complex configurations. When the combined architecture is different than NooN the calculation on “CF” is more accurate.

2-For MTTFS:

2.1-For simple architectures: 1oo1, 1oo2, 2oo2, 2oo3, 2oo4, 1oo2D, 1oo3, 1oo4, 1oo5, 3oo3, 4oo4, 2oo5, 1oo2div, 2oo2div, 1oo2R, 2oo2S, Kx1oo2, 3oo4, 3oo5, 4oo5, 1ooM (on both sheets “SIL” & “CF”).

-Method A: based on simple equations (ISA TR84).

-Method B: based on calculations with STR & PFS.

2.2-For combined voted groups (complex configurations).

-Option based on operations with STRs of the groups (addition, multiplication).

3-For PFH (high demand)

-Sheets “SIL” & “SIL2”: For calculations based on IEC-61508 equations.

Architectures: 1oo1, 1oo2, 1oo2D, 2oo2, 2oo3, 1oo3, 3oo3, 4oo4.

SILcet

3 List of Architectures

Table 2 - Safety Architectures versus Hardware Fault Tolerance

	Route 1H	Route 2H		
			Low demand	High demand
	HFT	HFT	Maximum SIL	Maximum SIL
1oo1	0	0	2	1
1oo2	1	1	3	3
2oo2	0	0	2	1
2oo3	1	1	3	3
2oo4	2	2	4	--
1oo2div	1	1	3	--
2oo2div	0	0	2	--
1oo2R	1	1	3	--
2oo2S	1	1	3	--
1oo2D	1	1	3	3
1oo3	2	2	4	4
1oo4	3	3	4	--
1oo5	4	4	4	--
3oo3	0	0	2	1
4oo4	0	0	2	1
2oo5	2	2	4	--
5x1oo2	1	1	3	--
3oo4	1	1	3	--
3oo5	2	2	4	--
4oo5	1	1	3	--
1oo6	5	5	4	--

With diverse components (1oo2div, 2oo2div)

2x1oo2 (in parallel) / 2x2oo2 (in series) (1oo2R, 2oo2S)

Modificable Kx1oo2 (5x1oo2)

Modificable 1ooM (M>5) (1oo6)

PFDavg for Low Demand.

PFH for High Demand.

More complex configurations on sheet “CF”

4 Formulas to calculate PFD on sheet SIL

4.1 Formulas with identical components (sheet SIL)

PFDavg (1oo1) = $\frac{Cpt\ .\ \lambda_{DU}\ .\ TI}{2} + \frac{(1-Cpt)\ .\ \lambda_{DU}\ .\ LT}{2} + \lambda_{DD}\ .\ MTTR_{DD}$

PFDavg (1oo2) = $\frac{[(1-\beta).\ Cpt\ .\ \lambda_{DU}\ .\ TI]^2}{3} + \frac{[(1-\beta).\ (1-Cpt)\ .\ \lambda_{DU}\ .\ LT]^2}{3} +$

$\frac{\beta\ .\ Cpt\ .\ \lambda_{DU}\ .\ TI}{2} + \frac{\beta\ .\ (1-Cpt)\ .\ \lambda_{DU}\ .\ LT}{2}$

$\beta_{MooN} = \beta_{1oo2}$ x Factor (β entered into cells of SILcet must be for architecture 1oo2 (e.g. 5%). This beta value is automatically multiplied by a factor, based on the selected architecture, according to IEC-61508 part 6 – Annex D) (see Table D-5 on sheet "SIL").

Note: If needed SILcet allows you to add other terms to consider bypasses, etc.

PFDavg (2oo2) = $(1-\beta).\ Cpt\ .\ \lambda_{DU}\ .\ TI + (1-\beta).\ (1-Cpt)\ .\ \lambda_{DU}\ .\ LT +$

2. (1-β). $\lambda_{DD}\ .\ MTTR_{DD} + \frac{\beta\ .\ Cpt\ .\ \lambda_{DU}\ .\ TI}{2} + \frac{\beta\ .\ (1-Cpt)\ .\ \lambda_{DU}\ .\ LT}{2}$ (by default β_{2oo2} = 0)

$\beta_{2oo2} = \beta_{1oo2}$ x Factor. By default this factor is equal to 0 on IEC Table D-5. This multiplier could be changed on Table D-5 on sheet "SIL" (cell AU641).

PFDavg (2oo3) = $[(1-\beta).\ Cpt\ .\ \lambda_{DU}\ .\ TI]^2 + [(1-\beta).\ (1-Cpt)\ .\ \lambda_{DU}\ .\ LT]^2 +$
$\frac{\beta\ .\ Cpt\ .\ \lambda_{DU}\ .\ TI}{2} + \frac{\beta\ .\ (1-Cpt)\ .\ \lambda_{DU}\ .\ LT}{2}$

PFDavg (2oo4) = $[(1-\beta).\ Cpt\ .\ \lambda_{DU}\ .\ TI]^3 + [(1-\beta).\ (1-Cpt)\ .\ \lambda_{DU}\ .\ LT]^3$
$+ \frac{\beta\ .\ Cpt\ .\ \lambda_{DU}\ .\ TI}{2} + \frac{\beta\ .\ (1-Cpt)\ .\ \lambda_{DU}\ .\ LT}{2}$

PFDavg (MooN) = $\frac{N!}{(N-M+1)!\ .(M-1)!}\ \{ \frac{[(1-\beta).\ Cpt\ .\ \lambda_{DU}\ .\ TI]^{N-M+1}}{N-M+2} +$

$\frac{[(1-\beta).\ (1-Cpt)\ .\ \lambda_{DU}\ .\ LT]^{N-M+1}}{N-M+2} \} + \frac{\beta\ .\ Cpt\ .\ \lambda_{DU}\ .\ TI}{2} + \frac{\beta\ .\ (1-Cpt)\ .\ \lambda_{DU}\ .\ LT}{2}$

Note: PFDavg for architecture 1oo2D is calculated based on IEC-61508 (part 6 – Annex B) including TI and LT terms ($\beta_D = \beta/2$; K=0,98).

PFDavg (NooN) = $N \cdot \frac{(1-\beta) \cdot Cpt \cdot \lambda_{DU} \cdot TI}{2} + N \cdot \frac{(1-\beta) \cdot (1-Cpt) \cdot \lambda_{DU} \cdot LT}{2}$

$+ N \cdot (1-\beta) \cdot \lambda_{DD} \cdot MTTR_{DD} + \frac{\beta \cdot Cpt \cdot \lambda_{DU} \cdot TI}{2} + \frac{\beta \cdot (1-Cpt) \cdot \lambda_{DU} \cdot LT}{2}$

Other formulas:

Architecture 1oo2R (redundant 1oo2) and Kx1oo2: Two 1oo2 in parallel and K legs 1oo2 in parallel.

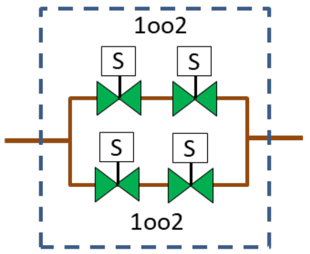
PFDavg (1oo2R) $= 2 \cdot \frac{[(1-\beta) \cdot Cpt \cdot \lambda_{DU} \cdot TI]^2}{3} + 2 \cdot \frac{[(1-\beta) \cdot (1-Cpt) \cdot \lambda_{DU} \cdot LT]^2}{3} +$

$\frac{\beta \cdot Cpt \cdot \lambda_{DU} \cdot TI}{2} + \frac{\beta \cdot (1-Cpt) \cdot \lambda_{DU} \cdot LT}{2}$

PFDavg (Kx1oo2) $= K \cdot \frac{[(1-\beta) \cdot Cpt \cdot \lambda_{DU} \cdot TI]^2}{3} + K \cdot \frac{[(1-\beta) \cdot (1-Cpt) \cdot \lambda_{DU} \cdot LT]^2}{3} +$

$\frac{\beta \cdot Cpt \cdot \lambda_{DU} \cdot TI}{2} + \frac{\beta \cdot (1-Cpt) \cdot \lambda_{DU} \cdot LT}{2}$

1oo2R



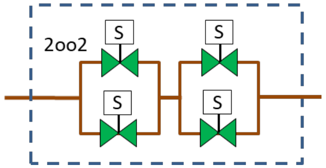
Architecture 2oo2S: Two 2oo2 in series.

PFDavg (2oo2S) = $\{ (1-\beta) \cdot Cpt \cdot \lambda_{DU} \cdot TI + (1-\beta) \cdot (1-Cpt) \cdot \lambda_{DU} \cdot LT +$

$2 \cdot (1-\beta) \cdot \lambda_{DD} \cdot MTTR_{DD} \}^2 + \frac{\beta \cdot Cpt \cdot \lambda_{DU} \cdot TI}{2} + \frac{\beta \cdot (1-Cpt) \cdot \lambda_{DU} \cdot LT}{2}$

Note: The result of this formula is conservative compared to the exact calculation made with integrals. When a more accurate calculation is required, the "CF" sheet can be used.

2oo2S



Example:

Select		SD	SU	DD	DU	Type	SC	Select	PFDavg	SIL (pfd)	HFT
sensor	PT-100A/B	3040	160	3040	160	2	3	2oo3	2,06E-04	3	1
logicsolver	Safety PLC	912	48	912	48	2	3	1oo1	9,68E-04	3	0
actuator	XV-300A/B	0	6200	0	6200	1		1oo2	3,06E-02	1	1
								1oo1	--	--	0
							SIL-3		3,18E-02	SIL-1	Route 1H
								Reached SIL=		SIL-1	

Select		Cpt	TI (y)	LT (y)	β	$MTTR_{DD}$	Select	PFDavg	SIL (pfd)	HFT
sensor	PT-100A/B	90%	4	15	5%	12	2oo3	2,06E-04	3	1
logicsolver	Safety PLC	95%	4	15	2%	12	1oo1	9,68E-04	3	0
actuator	XV-300A/B	70%	1	15	10%	12	1oo2	3,06E-02	1	1
		90%	1	15	0%	12	1oo1	--	--	0
								3,18E-02	SIL-1	Route 1H
							Reached SIL=		SIL-1	

4.2 Formulas with diverse components (sheet SIL)

PFDavg (1oo2 div) = $\frac{(1-\beta_1).\ Cpt_1\ .TI_1\ .\lambda_{1DU}\ .\ \ (1-\beta_2)\ .Cpt_2\ .TI_2\ .\ \lambda_{2DU}}{3}$ +

$\frac{(1-\beta_1).(1-Cpt_{1)}\ .LT_1\ .\ \lambda_{1DU}\ .\ (1-\beta_2).(1-Cpt_2)\ .LT_2\ .\ \lambda_{2DU}}{3}$ +

$(\beta_1\ .\ \beta_2\ .\ Cpt_1\ .\ Cpt_2\ .\ TI_1\ .\ TI_2\ .\ \lambda_{1DU}\ .\ \lambda_{2DU})^{1/2}\ /\ 2$ +

$(\beta_1\ .\ \beta_2\ .\ (1\text{-}Cpt_1)\ .\ (1\text{-}Cpt_2)\ .\ LT_1\ .\ LT_2\ .\ \lambda_{1DU}\ .\ \lambda_{2DU})^{1/2}\ /\ 2$

Normally use the same β for both components ($\beta_1 = \beta_2$).

PFDavg (2oo2 div) = $\frac{(1-\beta_1).Cpt_1\ .TI_1\ .\lambda_{1DU} +\ (1-\beta_2).Cpt_2\ .TI_2\ .\ \lambda_{2DU}}{2}$ +

$\frac{(1-\beta_1).(1-Cpt_{1)}\ .LT_1\ .\ \lambda_{1DU} +\ (1-\beta_2).(1-Cpt_2)\ .LT_2\ .\ \lambda_{2DU}}{2}$ +

$(\beta_1\ .\ \beta_2\ .\ Cpt_1\ .\ Cpt_2\ .\ TI_1\ .\ TI_2\ .\ \lambda_{1DU}\ .\ \lambda_{2DU})^{1/2}\ /\ 2$ +

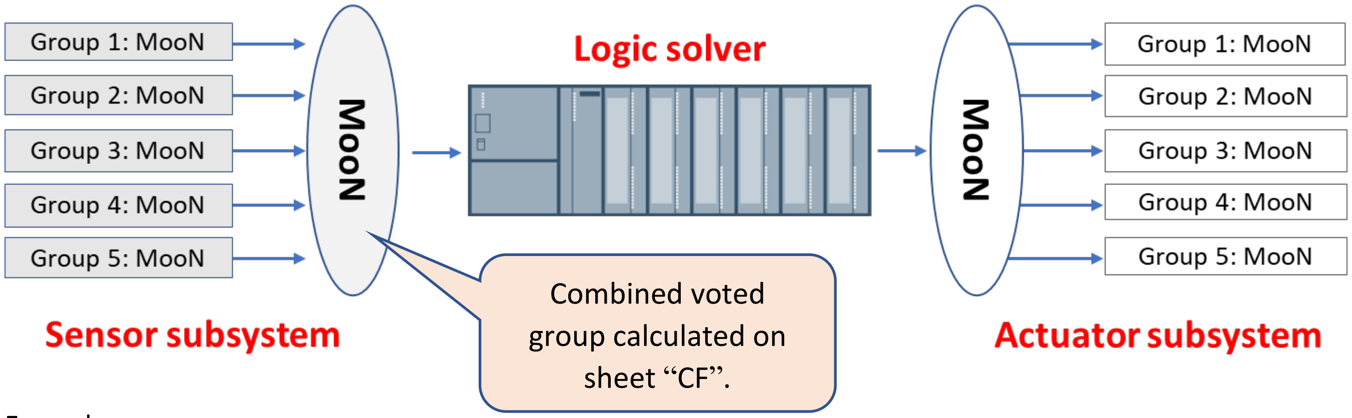
$(\beta_1\ .\ \beta_2\ .\ (1\text{-}Cpt_1)\ .\ (1\text{-}Cpt_2)\ .\ LT_1\ .\ LT_2\ .\ \lambda_{1DU}\ .\ \lambda_{2DU})^{1/2}\ /\ 2$ (by default $\beta_{2oo2} = 0$)

$\beta_{2oo2} = \beta_{1oo2}$ x Factor. By default this factor is equal to 0 on IEC Table D-5. This multiplier could be changed on Table D-5 on sheet "SIL" (cell AU641).

Example:

Select		Cpt	TI (y)	LT (y)	β	MTTRDD	MTTRs	OnOff	Select	PFDavg	SIL (pfd)	HFT
sensor	PT-100A	90%	4	15	5%	12	24	0	1oo2div	6,48E-04	3	1
sensor	Motor running	90%	4	15	5%	12	24	0	1oo2div	--	--	1
logicsolver	Safety PLC	95%	4	15	2%	12	24	0	1oo1	9,68E-04	3	0
actuator	XV-300A/B	70%	1	15	10%	12	24	0	1oo2	3,06E-02	1	1
									1oo1	--	--	0
										3,23E-02	SIL-1	Route 1H
										Reached SIL=	**SIL-1**	

5 Formulas to calculate PFD on sheet CF (Complex Functions)



Results from sheet “CF” (PFDavg and MTTFS) should be entered into SIF (on sheet SIL).

Example:

Select		SD	SU	DD	DU	Type	Select	PFDavg	MTTFS
sensor	PT-100A/B	550,0	550,0	550,0	550,0	2	1oo2	8,00E-04	53
sensor	TS-200A/B/C	0,0	1100,0	0,0	1100,0	1	2oo3	4,92E-03	419
sensor	Pushbutton		200,0		400,0	1	1oo1	1,26E-02	571
sensor							1oo1		
sensor							1oo1		
sensor_c		0,0	0,0	0,0	0,0		**2oo3**	5,42E-05	3.261
		(FITS only used for common cause)						SIL-3	

Select		Cpt	TI (y)	LT (y)	β	MTTRDD	MTTRs	OnOff	Select	PFDavg	MTTFS
sensor	PT-100A/B	90%	4	20	5%	12	24	0	1oo2	8,00E-04	53
sensor	TS-200A/B/C	80%	4	20	5%	12	24	0	2oo3	4,92E-03	419
sensor	Pushbutton	80%	4	20	0%	12	24	0	1oo1	1,26E-02	571
sensor		100%	4	20	0%	12	24	0	1oo1		
sensor		100%	4	20	0%	12	24	0	1oo1		
sensor_c		100%	4	20	0,0%				**2oo3**	5,42E-05	3.261
					info					SIL-3	

5.1 Method 1 based on integrals

First order approximation for PFD(t) derived from the fault tree is as follows:

$PFDg^{1oo1}$ (t) = (1-β). [$Cpt\ .\ \lambda_{DU}\ .\ t + (1 - Cpt)\ .\ \lambda_{DU}\ .\ t +\ \lambda_{DD}\ .\ MTTR_{DD}$] +

β. [$Cpt\ .\ \lambda_{DU}\ .\ t + (1 - Cpt)\ .\ \lambda_{DU}\ .\ t +\ \lambda_{DD}\ .\ MTTR_{DD}$]

a) $PFDg^{TI(1oo1)}$ (t) = (1-β). [$Cpt\ .\ \lambda_{DU}\ .\ t +\ \lambda_{DD}\ .\ MTTR_{DD}$] + β. [$Cpt\ .\ \lambda_{DU}\ .\ t +\ \lambda_{DD}\ .\ MTTR_{DD}$]

(for DU failures detected during proof tests)

b) $PFDg^{LT(1oo1)}$ (t) = (1-β). [$(1 - Cpt)\ .\ \lambda_{DU}\ .\ t$] + β. [$(1 - Cpt)\ .\ \lambda_{DU}\ .\ t$]

(for DU failures not detected during proof tests)

$\beta_{MooN} = \beta_{1oo2}$ x Factor (β entered into cells of SILcet must be for architecture 1oo2 (e.g. 5%). This beta value is automatically multiplied by a factor, based on the selected architecture, according to IEC-61508 part 6 – Annex D) (see Table D-5 on sheet "SIL").

<u>Average probability for **each group**</u>:

Averaging the equation over the proof test interval TI and the life time LT:

$$PFDavg^{1oo1} = \frac{1}{TI} \int_0^{TI} \mathrm{PFDg}\ (t)\ dt + \frac{1}{LT} \int_0^{LT} \mathrm{PFDg}\ (t)\ dt$$

$$PFDavg^{1oo2} = \frac{1}{TI} \int_0^{TI} (\mathrm{PFDg}\ (t))^2\ dt + \frac{1}{LT} \int_0^{LT} (\mathrm{PFDg}\ (t))^2\ dt$$

In the same way with other architectures (2oo2,2oo3,1oo3,1oo4,1oo5,2oo4,3oo3,4oo4,2oo5, 3oo4, 3oo5, 4oo5)

Notice that PFDavg calculated on sheet "CF" is more accurate than calculations on sheet "SIL", although the difference is normally very small. In combined architectures NooN there is not difference.

SILcet

<u>Average probability for **combined voted group**</u>: $PFD^{1oo2}(t) = PFDg_1(t) . PFDg_2(t) + PFDcc(t)$ $PFDcc(t) = \beta_{combined} . [Cpt . \lambda_{DU} . t + (1 - Cpt) . \lambda_{DU} . t]$ $PFDavg^{1oo2} = \frac{1}{TI} \int_0^{TI} (PFD_1(t) . PFD_2(t) + (PFDcc)_{TI}) dt + \frac{1}{LT} \int_0^{LT} (PFD_1(t) . PFD_2(t) + (PFDcc)_{LT}) dt$ $PFDavg^{2oo3} = \frac{1}{TI} \int_0^{TI} (PFD_1(t) . PFD_2(t) + PFD_1(t) . PFD_3(t) + PFD_2(t) . PFD_3(t) + (PFDcc)_{TI}) dt +$ $\frac{1}{LT} \int_0^{LT} (PFD_1(t) . PFD_2(t) + PFD_1(t) . PFD_3(t) + PFD_2(t) . PFD_3(t) + (PFDcc)_{LT}) dt$ Note: same calculations with integrals are made for 2oo2, 1oo3, 1oo4, 1oo5, 2oo4, 3oo3, 4oo4, 5oo5.	Notice that $\beta_{combined}$ affects to all groups, however β affects to each group.

5.2 Method 2 based on PFDavg of each group

Note: This method is valid when adding average probabilities but not when multiplying them since the integral of [PFD_1 x PFD_2] is not equal to the multiplication of the integrals of each factor. Therefore, this method 2 is not always correct but we include it in SILcet for comparative purposes and because it is a preferred method for many users.

Correction factor = Cf (by default = 1).

$PFDavgcc = \beta_{combined} \cdot [\, Cpt \, . \, \lambda_{DU} \, . \, TI/2 + (1 - Cpt) \, . \, \lambda_{DU} \, . \, LT/2]$ PFDavg (1oo2) = Cf . $PFDavg_1$. $PFDavg_2$ + PFDavgcc PFDavg (2oo2) = $PFDavg_1$ + $PFDavg_2$ + PFDavgcc (by default PFD_{2oo2} = 0). PFDavg (2oo3) = Cf . ($PFDavg_1$. $PFDavg_2$ + $PFDavg_1$. $PFDavg_3$ + $PFDavg_2$. $PFDavg_3$) + PFDavgcc PFDavg (1oo3) = Cf . $PFDavg_1$. $PFDavg_2$. $PFDavg_3$ + PFDavgcc PFDavg (1oo4) = Cf . $PFDavg_1$. $PFDavg_2$. $PFDavg_3$. $PFDavg_4$ + PFDavgcc PFDavg (1oo5) = Cf . $PFDavg_1$. $PFDavg_2$. $PFDavg_3$. $PFDavg_4$. $PFDavg_5$ + PFDavgcc PFDavg (2oo4) = Cf . ($PFDavg_1$. $PFDavg_2$. $PFDavg_3$ + $PFDavg_1$. $PFDavg_2$. $PFDavg_4$ + $PFDavg_1$. $PFDavg_3$. $PFDavg_4$ + $PFDavg_2$. $PFDavg_3$. $PFDavg_4$) + PFDavgcc PFDavg (3oo3) = $PFDavg_1$ + $PFDavg_2$ + $PFDavg_3$ + PFDavgcc (by default PFD_{3oo3} = 0). PFDavg (4oo4) = $PFDavg_1$ + $PFDavg_2$ + $PFDavg_3$ + $PFDavg_4$ + PFDavgcc (by default PFD_{4oo4} = 0). PFDavg (5oo5) = $PFDavg_1$ + $PFDavg_2$ + $PFDavg_3$ + $PFDavg_4$ + $PFDavg_5$ + PFDavgcc (by default PFD_{5oo5} = 0).	$\beta_{MooN} = \beta_{1oo2}$ x Factor (β entered into cells of SILcet must be for architecture 1oo2 (e.g. 5%). This beta value is automatically multiplied by a factor, based on the selected architecture, according to IEC-61508 part 6 – Annex D) (see Table D-5 on sheet "SIL"). $\beta_{2oo2} = \beta_{1oo2}$ x Factor. By default this factor is equal to 0 on IEC Table D-5. This multiplier could be changed on Table D-5 on sheet "SIL" (cell AV643).

6 Formulas to calculate MTTFS

There are 2 methods to calculate STR. Select Method A or B on sheet "SIL" or "CF".

6.1 Method A (on sheets SIL & CF)

This method is based on ISA TR84. For architectures MooN (M ≥ 2) it calculates the probability of a false trip with MTTR (PFS = MTTR x λ).

6.1.1 Calculation of STR for usual architectures (method A)

MTTRS (Mean Time To Repair Spurious) = 1 / STR / 8760 (in years) **STR (1oo1)** = $\lambda_S + \lambda_{DD}$ **STR (1oo2)** = $2 . (\lambda_S + \lambda_{DD}) + \beta . (\lambda_S + \lambda_{DD})$ **STR (2oo2)** = $2 . (\lambda_S + \lambda_{DD})^2 . MTTR + \beta . (\lambda_S + \lambda_{DD})$ (by default $\beta_{2oo2} = 0$) **STR (2oo3)** = $6 . (\lambda_S + \lambda_{DD})^2 . MTTR + \beta . (\lambda_S + \lambda_{DD})$ **STR (2oo4)** = $12 . (\lambda_S + \lambda_{DD})^3 . MTTR^2 + \beta . (\lambda_S + \lambda_{DD})$ **STR (2oo5)** = $20 . (\lambda_S + \lambda_{DD})^4 . MTTR^3 + \beta . (\lambda_S + \lambda_{DD})$ **STR (3oo4)** = $12 . (\lambda_S + \lambda_{DD})^2 . MTTR + \beta . (\lambda_S + \lambda_{DD})$ **STR (3oo5)** = $30 . (\lambda_S + \lambda_{DD})^3 . MTTR^2 + \beta . (\lambda_S + \lambda_{DD})$ **STR (4oo5)** = $20 . (\lambda_S + \lambda_{DD})^2 . MTTR + \beta . (\lambda_S + \lambda_{DD})$	(STR = Spurious Trip Rate) On sheet "CF" the calculations of STR **for combined voted group** is achieved in a different way (see next point). β can be removed from calculations of STR (see cell AS1 on sheet "SIL"). Note: λ_{DD} can be removed from the calculations by using the OnOff switch of column Z.

STR (1oo2 div) = $\lambda_{1S} + \lambda_{1DD} + \lambda_{2S} + \lambda_{2DD} + ((\beta_1 . \beta_2 . (\lambda_{1S} + \lambda_{1DD}) . (\lambda_{2S} + \lambda_{2DD}))^{1/2}$ **STR (2oo2 div)** = $(\lambda_{1S} + \lambda_{1DD}).(\lambda_{2S} + \lambda_{2DD}).(MTTR_1 + MTTR_2) +$ $((\beta_1 . \beta_2 . (\lambda_{1S} + \lambda_{1DD}) . (\lambda_{2S} + \lambda_{2DD}))^{1/2}$ (by default $\beta_{2oo2} = 0$) For other architectures (1ooN, NooN) calculations are made with general formula: $STR_{MooN} = (N! / (N-M)!) . MTTR^{M-1} . (\lambda_S + \lambda_{DD})^M + \beta . (\lambda_S + \lambda_{DD})$	

6.2 Method B (on sheets SIL & CF)

This method considers the complete fault tree to calculate the probability of a false trip (PFS), therefore it differentiates detected failures from undetected failures. For architectures 1ooN the method A & B are identical but for architectures MooN (M $\geq$ 2) this method is more accurate.

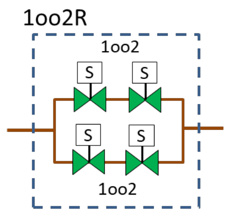
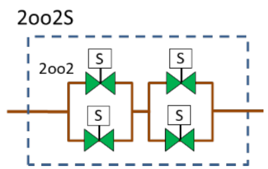
6.2.1 Calculation of STR for usual architectures (method B)

MTTRS (Mean Time To Repair Spurious) = 1 / STR / 8760 (in years) (STR = Spurious Trip Rate) **STR (1oo1)** = $\lambda_S + \lambda_{DD}$ Note: λ_{DD} can be removed from the calculations by using the OnOff switch of column Z. **STR (1ooN)** = $N.(1-\beta).(\lambda_S + \lambda_{DD}) + \beta.(\lambda_S + \lambda_{DD})$ (N>1) **STR (1oo2D)** = $2.(1-\beta).\lambda_{SU} + 2.(1-\beta).(\lambda_{SD} + \lambda_{DD}).\mathrm{PFSavg} + \beta.(\lambda_S + \lambda_{DD})$ **STR (2oo2)** = 2 . STR . PFS_{avg} + $\beta.(\lambda_S + \lambda_{DD})$ (by default $\beta_{2oo2} = 0$) **STR (2oo3)** = 6 . STR . PFS_{avg} + $\beta.(\lambda_S + \lambda_{DD})$ **STR (2oo4)** = 12 . STR . $(PFS_{avg})^2$ + $\beta.(\lambda_S + \lambda_{DD})$ **STR (2oo5)** = 20 . STR . $(PFS_{avg})^3$ + $\beta.(\lambda_S + \lambda_{DD})$ **STR (3oo4)** = 12 . STR . PFS_{avg} + $\beta.(\lambda_S + \lambda_{DD})$ **STR (3oo5)** = 30 . STR . $(PFS_{avg})^2$ + $\beta.(\lambda_S + \lambda_{DD})$ **STR (4oo5)** = 20 . STR . PFS_{avg} + $\beta.(\lambda_S + \lambda_{DD})$	PFS_x = Probability of device x having a safe fail. STR_x = Spurious Trip Rate of device x MTTRs = Mean Time To Repair a safe failure of a device (including time to restore to normal operation) First order approximation for PFS(t) derived from the fault tree is as follows: PFS(t) = $(1-\beta).(\lambda_{SD} + \lambda_{DD})$. MTTRs + $(1-\beta)$. Cpt . λ_{SU} . t + $(1-\beta)$. (1-Cpt) . λ_{SU} . t PFS_{avg} = average PFS without common cause term. By averaging PFS(t) over the appropriate time intervals we can obtain: PFS_{avg} = $(1-\beta).(\lambda_{SD} + \lambda_{DD})$. MTTRs + $(1-\beta)$. Cpt . λ_{SU} . TI/2 + $(1-\beta)$. (1-Cpt) . λ_{SU} . LT/2 β can be removed from calculations of STR (see cell AS1 on sheet "SIL"). Note: λ_{DD} can be removed from the calculations by using the OnOff switch of column Z.

Calculation of STR for different components – Method B (only on sheet SIL)

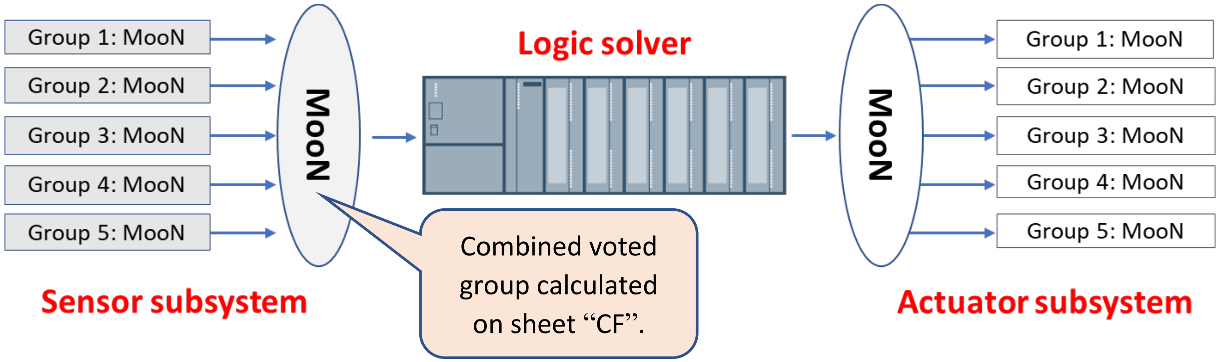
Note: The first component is in the odd row and the second one in the even row. **STR (1oo2 div)** = $STR_1 + STR_2 + STRcc = \lambda_{1S} + \lambda_{1DD} + \lambda_{2S} + \lambda_{2DD} + ((\beta_1 . \beta_2 . (\lambda_{1S} + \lambda_{1DD}) . (\lambda_{2S} + \lambda_{2DD}))^{1/2}$	Normally use the same β for both components ($\beta_1 = \beta_2$).
STR (2oo2 div) = $STR_1 . PFS_2 + STR_2 . PFS_1 + STRcc = (\lambda_{1S} + \lambda_{1DD}).PFS_2 + (\lambda_{2S} + \lambda_{2DD}).PFS_1 + ((\beta_1 . \beta_2 . (\lambda_{1S} + \lambda_{1DD}) . (\lambda_{2S} + \lambda_{2DD}))^{1/2}$ (by default $\beta_{2oo2} = 0$)	By default, multiplier for beta on IEC Table D-5 is equal to 0 for 2oo2. This multiplier could be changed on Table D-5 on sheet "SIL" (cell AV643).

Other formulas:

Architecture 1oo2R (K=2) and Kx1oo2: Two 1oo2 in parallel and K legs 1oo2 in parallel. Method A → **STR (Kx1oo2)** = $4.K.(K-1).(\lambda_S + \lambda_{DD})^2 .MTTR + \beta .(\lambda_S + \lambda_{DD})$ Method B → **STR (Kx1oo2)** = $4.K.(K-1) . STR . PFS_{avg} + \beta .(\lambda_S + \lambda_{DD})$	
Architecture 2oo2S: Two 2oo2 in series. Method A → **STR (2oo2S)** = $4 .(\lambda_S + \lambda_{DD})^2 .MTTR + \beta .(\lambda_S + \lambda_{DD})$ Method B → **STR (2oo2S)** = $4 . STR . PFS_{avg} + \beta .(\lambda_S + \lambda_{DD})$	

6.3 Calculation of MTTFS of combined voted groups

6.3.1 Calculation of STR for combined groups on sheet CF (based on operations with STRs)



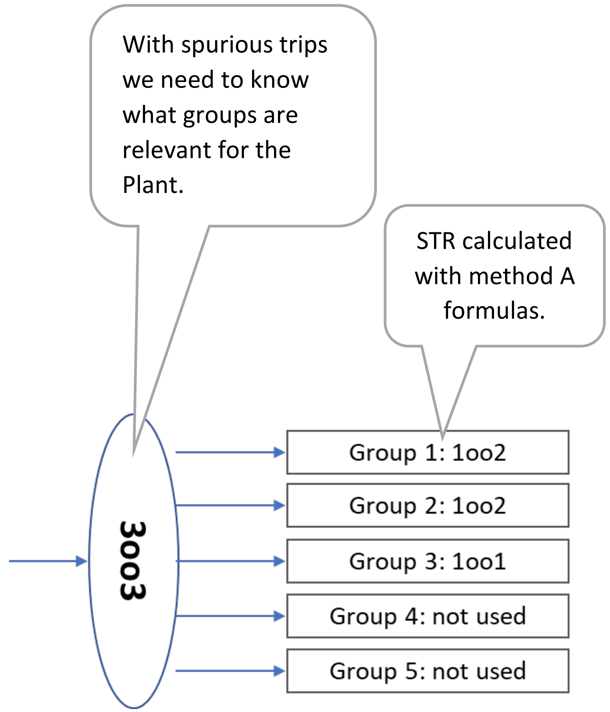
It's important to know what groups are relevant for the Plant. There are 2 options selectable by the user:

1-Addition of STRs of the relevant groups: $\mathbf{STR_{combined}} = STR_1 + STR_2 + \dots + STR_N + \beta_{combined} \cdot (\lambda_S + \lambda_{DD})$

Groups not relevant for the Plant can be removed from the addition.

2-Multiplication of STRs of relevant groups: $\mathbf{STR_{combined}} = STR_1 \cdot STR_2 \cdot \dots \cdot STR_N + \beta_{combined} \cdot (\lambda_S + \lambda_{DD})$

Groups not relevant for the Plant can be removed from the multiplication.



Let's see an example to understand options 1 and 2.

We have a water feed pump for 2 different cooling lines to a vessel:

Group 1: For the main line we have a 1oo2 architecture with 2 "fail to open" valves in parallel (it's a 1oo2 logic because both valves open when de-energized).

Group 2: For the secondary line we have a 1oo2 architecture with 2 "fail to open" valves in parallel (it's a 1oo2 logic because both valves open when de-energized).

Group 3: For the pump we have a 1oo1 logic.

We assume there is not common cause factor.

Case 1: If the trip of any of the groups is a problem for the Plant, then the overall STR is the addition of the individual STR.

Select	PFDavg	STR	Calculate?	MTTFS
1oo2	1,09E-04	5,78E-06	yes	20
1oo2	1,09E-04	5,78E-06	yes	20
1oo1	1,23E-02	2,89E-06	yes	40
1oo1			yes	
1oo1			yes	
3oo3	1,25E-02	Select >	Add STR	8

Case 2: If a false trip of any of the valves of group 2 is not an issue then the overall STR is the addition of STR of groups 1 and 3.

Select	PFDavg	STR	Calculate?	MTTFS
1oo2	1,09E-04	5,78E-06	yes	20
1oo2	1,09E-04	5,78E-06	no	20
1oo1	1,23E-02	2,89E-06	yes	40
1oo1			yes	
1oo1			yes	
3oo3	1,25E-02	Select >	Add STR	13

Case 3: If the trip of all groups is not an issue for the Plant then the overall STR is calculated by multiplying the three STR.

Select	PFDavg	STR	Calculate?	MTTFS
1oo2	1,09E-04	5,78E-06	yes	20
1oo2	1,09E-04	5,78E-06	yes	20
1oo1	1,23E-02	2,89E-06	yes	40
1oo1			yes	
1oo1			yes	
3oo3	1,25E-02	Select >	Multiply	>50000

SILcet

6.4 Formulas to calculate PFH (high demand)

SILcet uses the equations of IEC-61508 (part 6, Annex B).

PFH_G (1oo1) = λ_{DU} **PFH_G (2oo2) = 2 .** λ_{DU} **PFH_G (NooN) = N .** λ_{DU}	
PFH_G (1oo2) = $2 . [(1-\beta_D). \lambda_{DD} + [(1-\beta). \lambda_{DU}] . (1-\beta). \lambda_{DU} . t_{CE} + \beta. \lambda_{DU}$ $t_{CE} = [\frac{Cpt . \lambda_{DU} . TI}{2} + \frac{(1-Cpt) . \lambda_{DU} . LT}{2} + \lambda_{DD} . MTTR_{DD}] . 1/\lambda_D$	β_D=50% of β (modificable in column AF on sheet SIL).
PFH_G (1oo2D) = $2 . [(1-\beta_D). \lambda_{DD} + [(1-\beta). \lambda_{DU} + \lambda_{SD}] . (1-\beta). \lambda_{DU} . t'_{CE} + 2 . (1-K) . \lambda_{DD} + \beta. \lambda_{DU}$ $t'_{CE} = [\frac{Cpt . \lambda_{DU} . TI}{2} + \frac{(1-Cpt) . \lambda_{DU} . LT}{2} + (\lambda_{DD} + \lambda_{SD}) . MTTR_{DD}] . 1/(\lambda_{DU} + \lambda_{DD} + \lambda_{SD})$	K=0,98
PFH_G (2oo3) = $6 . [(1-\beta_D). \lambda_{DD} + [(1-\beta). \lambda_{DU}] . (1-\beta). \lambda_{DU} . t_{CE} + \beta. \lambda_{DU}$	
PFH_G (1oo3) = $6 . [(1-\beta_D). \lambda_{DD} + [(1-\beta). \lambda_{DU}]^2 . (1-\beta). \lambda_{DU} . t_{CE} . t_{GE} + \beta. \lambda_{DU}$ $t_{GE} = [\frac{Cpt . \lambda_{DU} . TI}{3} + \frac{(1-Cpt) . \lambda_{DU} . LT}{3} + \lambda_{DD} . MTTR_{DD}] . 1/\lambda_D$	