The POS Model For Common Cause Failure Quantification: Progress In Parameter Estimation And Comprehensive Documentation

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Outline

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- Comparison of POS results with generic CCF data
- Concluding remarks

Introduction

- Experience from probabilistic safety assessments (PSA) has shown that, in particular for highly redundant components or systems, common cause failures dominate the results of PSA.
- On the other hand, the number of really observed events is limited, especially with respect to events involving failures of all or at least many redundant components or systems.

German practice for the assessment of NPPs

- General procedure laid down in regulatory guidance documents
- No specific approach or model prescribed
- A clearly prescribed derivation of model parameters from operating experience is required
- A variety of models has been used in the analyses provided by the utilities and evaluated by the independent experts

POS model : Rationale and objectives

- **The question can be raised whether an approach aiming at modelling the entire CCF process from the point in time of the root cause impact to failures taking effect or being detected in the common cause component group (CCCG) in a more mechanistic manner could support and complement the established modelling which is mostly directly aiming at failure probabilities.**

POS model: Model description

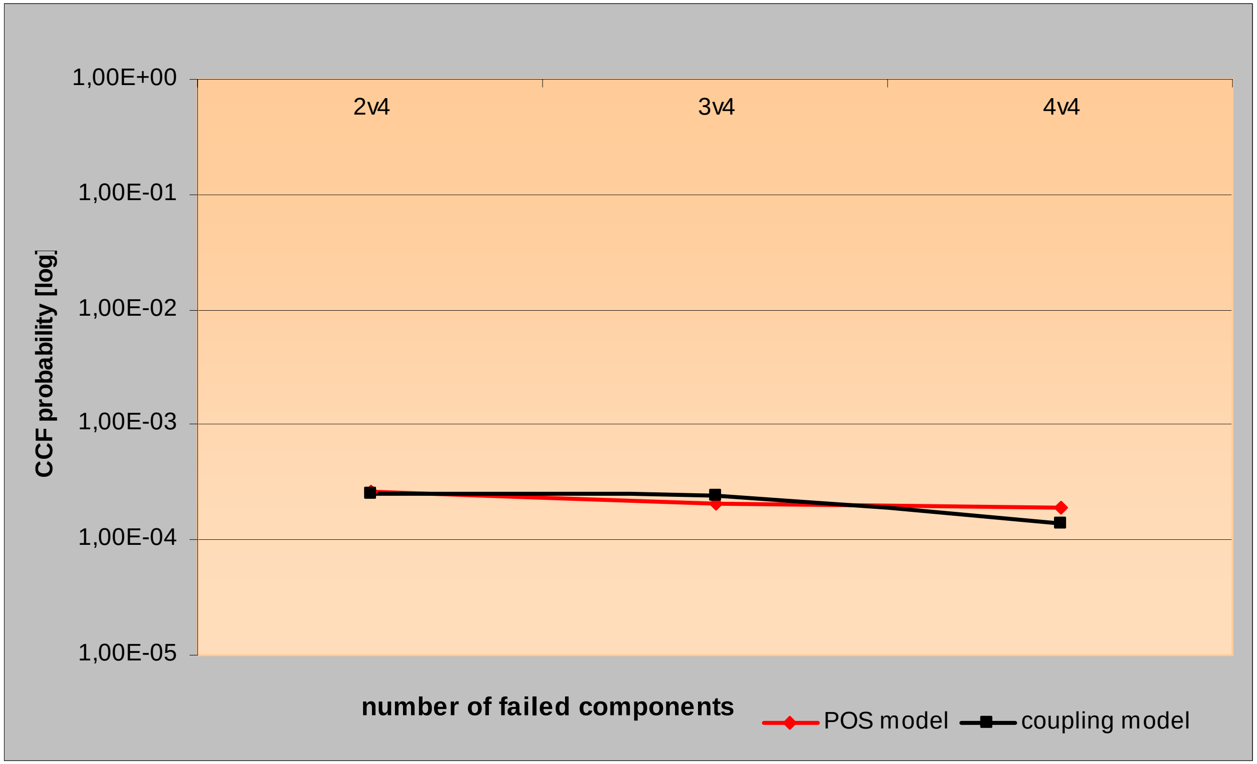
Strategy:

- **The model is supposed to account for cases, in which not all components are sharing the same cause [as implied for example in the Binomial Failure Rate Model (BFR)].**
- **Delayed failures shall be covered as well as causes leading to immediate failure.**
- **The approach shall include a sound basis for treatment of highly redundant systems.**
- **Technically the modelling shall use the proven instrument of stochastic simulation.**

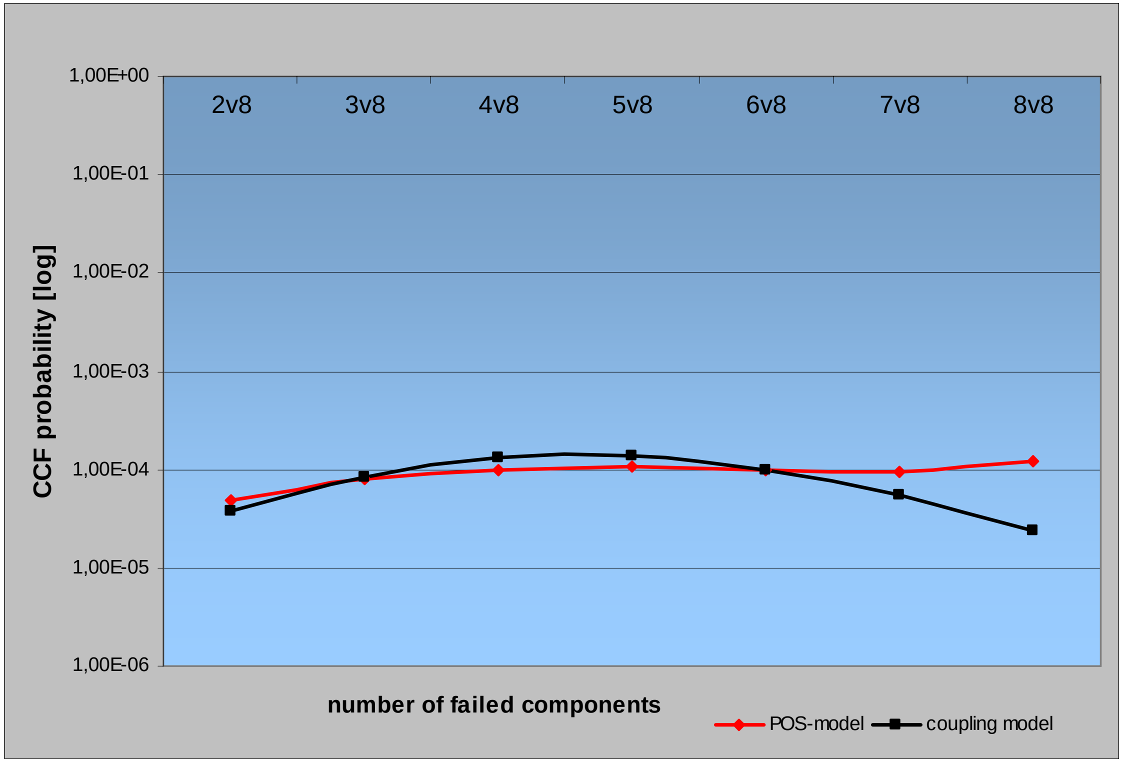
Model Structure of the POS model

- Time of CCF impact, simulated with a constant CCF impact rate,
- Number of components of the CCCG affected by the impact and subsequently failing immediately or time-delayed,
- Times of failure of the impacted components,
- Time of detection of the CCF process by inspection or functional testing,
- Calculation of times of unavailability.

CCF probabilities for plate valves in German NPPs obtained with the POS model compared to generic data based on the coupling model (r = 4)



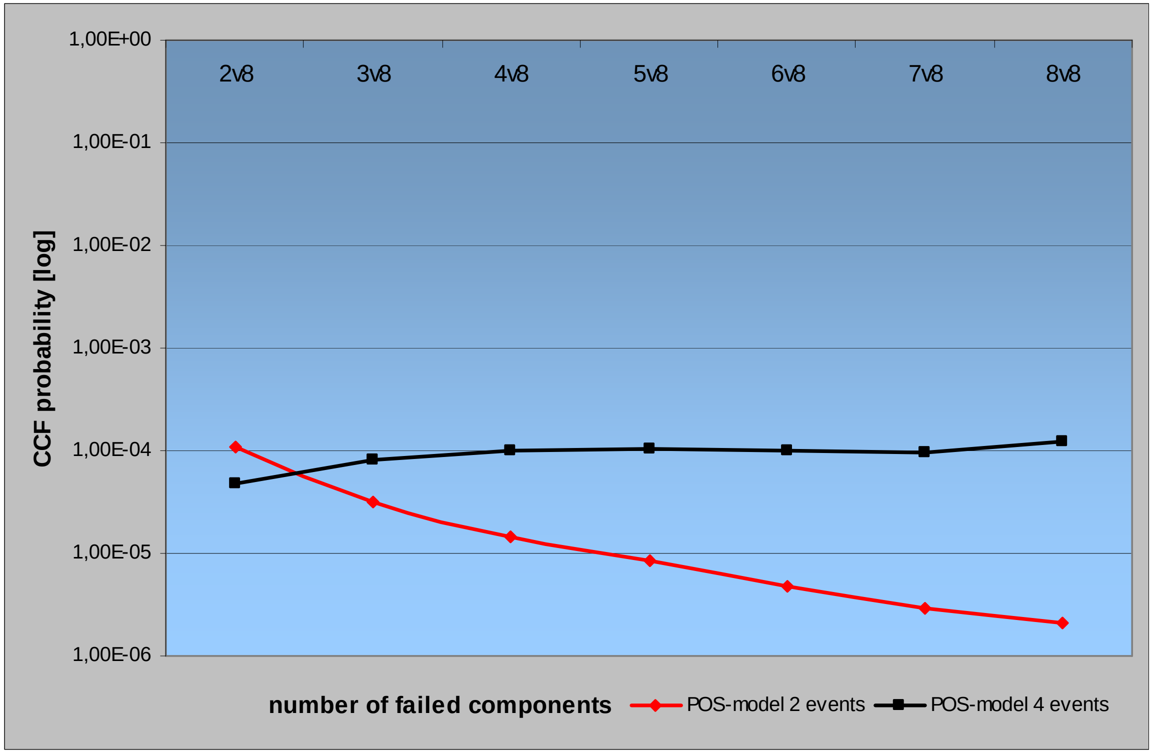
CCF probabilities for plate valves in German NPPs obtained with the POS model compared to generic data based on the coupling model (r = 8)



Observed CCF events applicable to plate valves in German NPPs with corresponding observation time 3200 years

Event Nr.	Degree of redundancy r	Number of failed components m	Number of failed components k	Expert opinions
1	6	2	2	unanimous
2	6	2	2	unanimous
3	4	4	4	unanimous
4	4 4	3 4	3 3	4 out of 6 experts 2 out of 6 experts

CCF probabilities for plate valves in German NPPs obtained with the POS model based on the events 1 and 2 from Table 1 only compared to the results based on all 4 events



POS model : comprehensive documentation

A comprehensive report on the POS model has been filed and is presently being edited (draft available).

Three aspects covered in the report shall be addressed here:

- Improved parameter estimation,
- Test of parameter estimation,
- Concept for quantitative CCF model comparison.

Parameter estimation framework (1)

- N(m,r) : number of events with m-out-of-r components affected
- Winst proportional to

$$\Sigma\ (Nn(m,m)*(1- Wdel/(1 + Wdel)) + 0,5)$$

- Wdel : conditional probability to have an event k = m due to delayed failures (can be obtained from the code by setting a = 1 and r = m)

Parameter estimation framework (2)

- N(m,r) : Number of events with m out-of-r components affected
- Estimate of W(m,r):
  - *W*(m,r) = (N(m,r) + 1/(r-1)) / (1 + Ne)
- Estimators for r_0 and a are based on the following model identities:
- $a = 1 - W(2,r)^{(1/(r-2))}$
- W(4,4)= a •(a + (1 – a) • (1 – exp(-3 / ro)))
- Details are given in the report.

POS model : Test of parameter estimation approach (1)

- The approach to estimating the model parameters from operating experience can be tested in a way that is peculiar for the POS-model. Due to its complex, process-oriented structure each simulation run produces all significant aspects characterising a CC event.

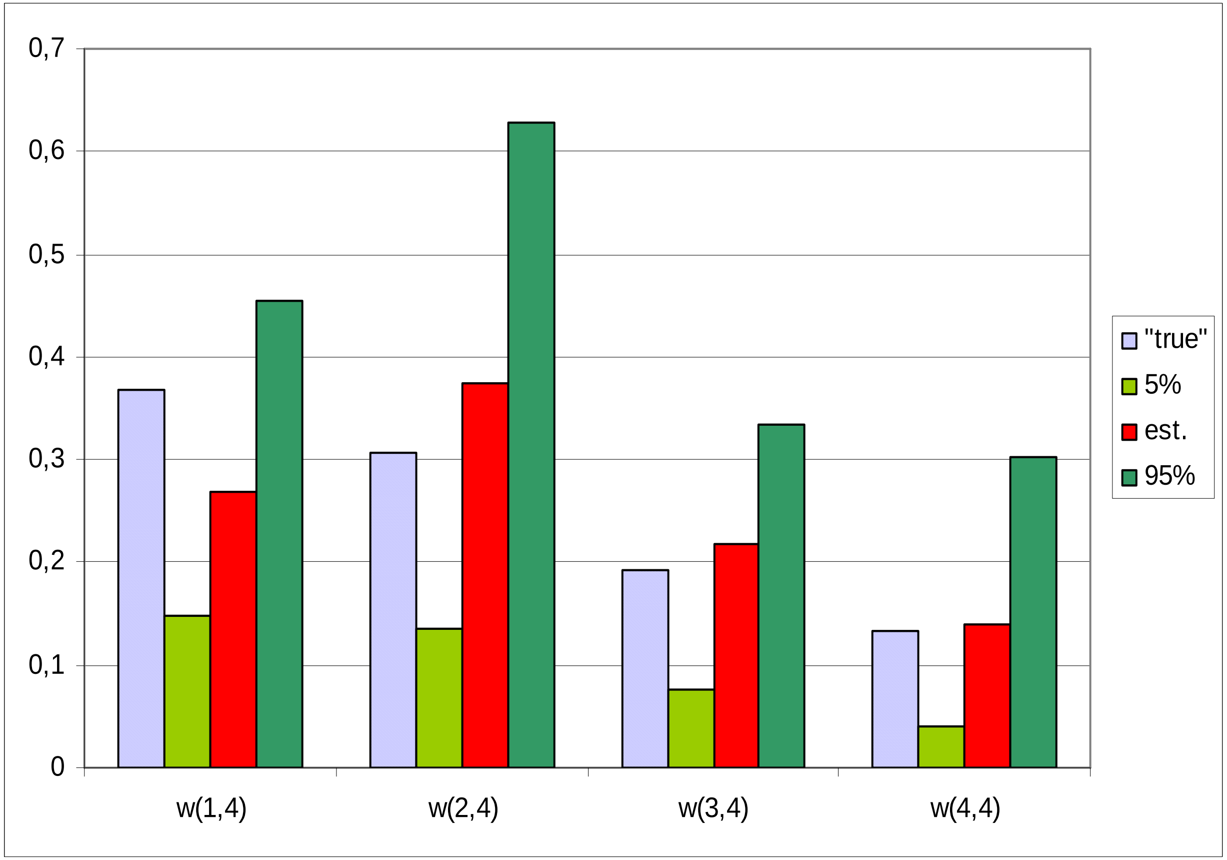
- This offers the following opportunity for testing the parameter estimation approach.

POS model : Test of parameter estimation approach (2)

- Firstly, for a given set of model parameters CCF events are simulated comprising key quantities, in particular the time of occurrence of the CCCG, the number of affected components and the number of failed components and the times of unavailability.
- In a second step the model parameters are estimated from the simulated data.
- Finally, the estimated model parameters are compared to the ”true” parameters where the degree of deviation is based on key model output like e.g. the probability of complete system failure. By generating a sufficiently large number of simulated events the uncertainty distribution of the model results can be obtained as a function of the number of simulated events.

POS model : Test of parameter estimation approach (3)

100 simulations, 3 events grouped together, a=0.35, r0=3.48, Winst = 0.25; TFK = 1year



POS model : Concept for quantitative CCF model comparison (1)

The importance of the CCF model used can be significant. A way to achieve such a comparison in a quantitative way is set out.

The basic idea is to split available operating experience and to use one part as a basis for estimating model parameters and make predictions of unavailabilities. These predictions can then be checked against the evidence in the complementary part of operating experience.

Analysis of a highly redundant system: events

Table 3. Observed CCF and degradations for combined impulse pilot valves (failure mode: does not open); adapted* from [8]

Event No.	No. failed components	No. degraded components	CCCG size *r*	Operation time T_B *[a]*
1	2	0	9	9
2	6	2	8	10
3	2	0	22	7
5*	1	15	16	9
6	2	5	16	7
7	2	10	12	6
8	7	1	8	10
9	1[a]	13[a]	14	9
11*	2	6	12	6
12	2	0	4	9

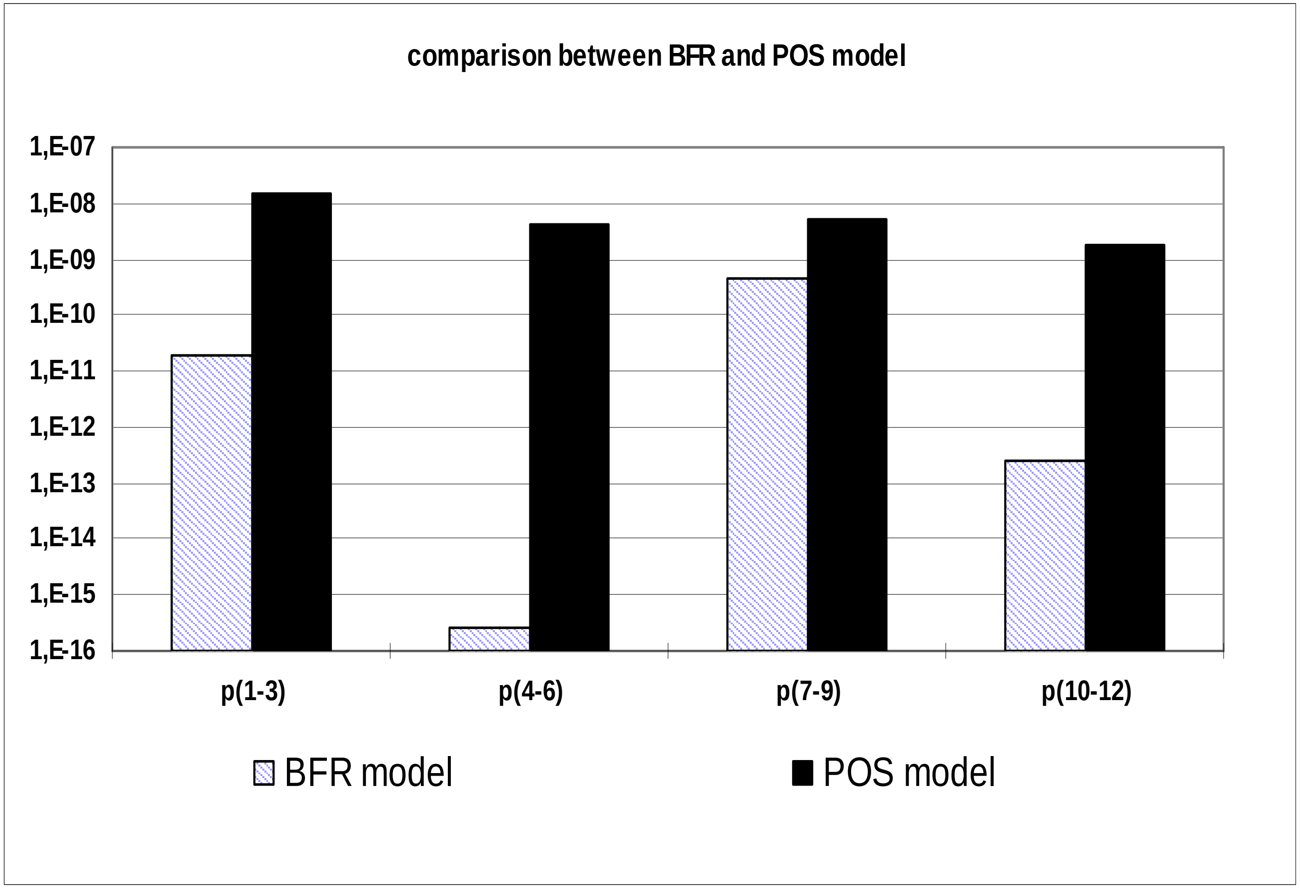
* H's events # 4 and 10 were omitted because with 1 failed and 0 degraded but not failed components they do not correspond to the definition of a CCF used in this paper, which is based on at least two components impacted by the common cause.

[a] In H's event # 9, one of the 14 components found degraded is assumed failed, because the analyses with the POS model presented here do not handle 'zero failure' events.

POS model : Concept for quantitative CCF model comparison (2)

Magnetic pilot valves and the associated operating experience as displayed before have been selected. From the 12 events the first three have been split. For this triple of events model parameters have been estimated for the BFR model (without lethal shocks) and the POS model. With both models the probability to find in nine with the redundancies the events with the observed failure multiplicities can be calculated as product of the probabilities for the individual events. This exercise was carried out also for events 4 to 6, 7 to 9 and 10 to 12 as basis for parameter estimation.

POS model :
Concept for quantitative CCF model comparison (3)



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POS model : Concept for quantitative CCF model comparison (4)

The point made with this little exercise is <u>not</u> to demonstrate the strengths of POS but to advocate a systematic CCF model comparison as part of a future benchmark!

- **More models need to be included.**
- **The comparison should be based on operating experience for several component types.**
- **The quantities used to evaluate the predictive strengths should be the outcome of a thoughtful selection.**

POS model : Model description

number of components sharing the cause (1):

- The following assumption is made for the conditional probability F(m,r) that component r+1 is sharing the same cause already observed for exactly m out of r components in a subsystem of size r:

- $F(m,r) = a + b \cdot (m - 2) / (r-2)$ $r > 3$ $F(2,2) = a$

- $b = (1 - a) \cdot (1 - \exp(-r / r_o))$ $c = \exp(-1 / r_0)$

POS model : Model description

number of components sharing the cause (2):

- rationale for the assumption on F(m,r).
- flexible: two free parameters can be adjusted to available evidence.
- the assumption guarantees that F(r,r) is approaching 1 with growing r. This has some plausibility, as one would expect naturally that if the cause was already observed e.g. at 19 out of 19 components it would be expected that number 20 would do so as well with probability close to certainty.
- simplicity, linear in m/r (a constant F(m,r>) would be too simple and fail in addressing operating experience properly.
- Simple stochastic models for the number of components sharing the cause are supporting the assumption.

POS model : Model description

number of components sharing the cause (3):

- **For a given F(m,r) the probabilities that exactly m out of r components share the cause is calculated from the following scheme:**

$W(2,2) = 1$

$W(3,3) = w(2,2) \cdot F(2,2)$ $W(2,3) = 1 – W(3,3) = W(2,2) \cdot (1 – F(2,2))$

$W(4,4) = W(3,3) \cdot F(3,3)$ $W(3,4) = W(2,3) \cdot F(2,3) + W(3,3) \cdot (1 – F(3,3))$

$W(2,4) = 1 – W(3,4) – W(4,4)$

etc.

POS model : Model description

number of components sharing the cause (4):

- **For the F(m,r) as introduced before the equations for W(m,r) read:**

W(2,2) = 1

W(3,3) = a W(2,3) = 1 – a

W(4,4)= a •(a + (1 – a) • (1 – exp(-3 / ro)))

W(3,4) = (1-a) • a + a •(1- a - (1 – a) • (1 – exp(-3 / ro)))

W(2,4) = 1 – 2 • (1-a) • a - a • a = 1 - 2 • a + a • a = (1 – a) 2

etc.

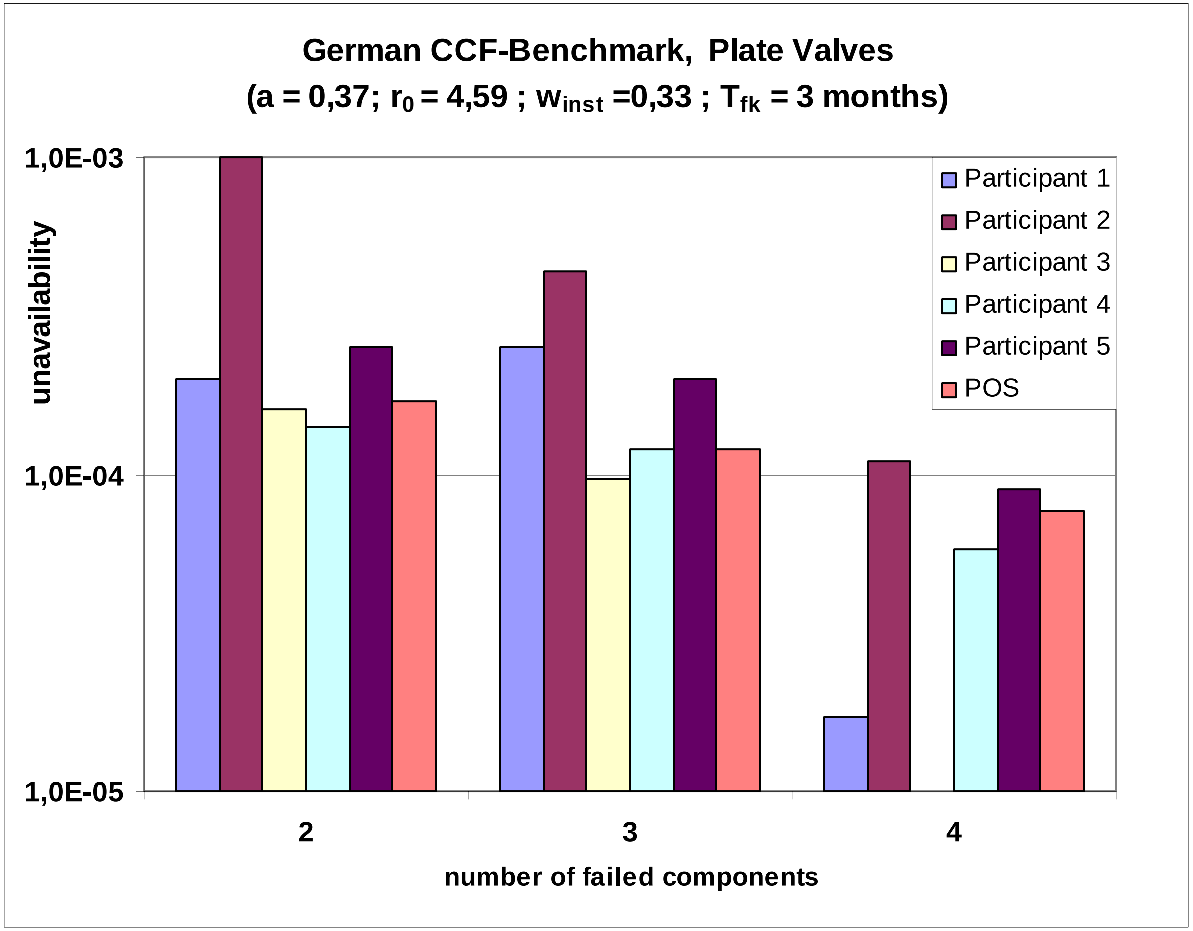
POS model : Applications (1)

Finally, 2 results of POS application are presented. In contrast to the results in the paper, the new parameter estimation method has been used.

The first application is a common cause benchmark on plate valves carried out in the 90ies. POS results fit well into the overall picture showing no outlying results.

The second example is on a highly redundant system of pilot valves. In contrast to many other approaches POS does not have a problem with extrapolation to high degrees of redundancy.

POS model : Applications (2)



POS model : Applications (3)
(Magnetic pilot valves, r = 22,
BFR, MCBFR results according to Hauptmanns)