

# Evaluation of Spurious Trip Rate of SIS dependent on demand rate

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*Abstract:* - Some of the spurious activations can lead to a hazardous state and therefore the plant cost can be extremely increased. For this reason the modelling of spurious activations in safety instruments systems (SIS) has been studied for over ten years and in different industry branches, for example: nuclear industry, offshore-onshore industry, process industry, .... In line with the important standard IEC 61508, SISs are generally classified into two types: low-demand systems and high-demand systems. This article focuses on the estimation of “spurious trip rate” (STR) and “mean time to failure spurious” ( $MTTF_{\text{Spurious}}$ ) for these two different system modes. The research is based on block diagrams and the Markov model and is exemplified by a simple system configuration: 1oo1.

*Key-Words:* - demand rate,  $MTTF_{\text{Spurious}}$ , spurious trip rate, 1oo1

## 1 Introduction

Safety instrumented systems (SISs) are widely used in the process industry to respond to hazardous events and unwanted events. If a hazardous situation occurs within an EUC (Equipment Under Control) and is detected, a demand is sent to safety system with a rate  $\lambda_{DE}$ . This demand serves to activate the safety function to achieve the EUC in safe state (Fig. 1).

The demand rate is not defined in standard IEC 61508 [1], but defined in the standard prEN ISO 13849-1 (2004) [17] as a frequency of demands for a safety-related action of a safety related part of a control system (SRP/CS).

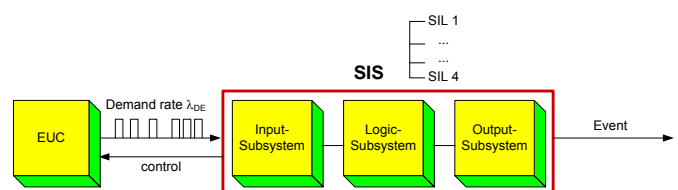


Fig. 1. EUC and SIS [14], [15]

According to the important standard IEC 61508 [1], SISs are classified into two types: low-demand systems and high-demand systems. A low-demand SIS has a frequency of demands not more than once per year and not more than twice the proof test frequency. Else, the SIS is considered as a high-demand system. However, there are no further discussions about the distinction between low- and high-demand systems. There is only a discussion

about the difference of the reliability evaluation between systems: Probability of Failure on Demand (PFD) for low-demand systems and Probability of Failure per Hour (PFH) for high-demand systems.

The SIS can be regarded from one of two different perspectives: safety or availability. From the point of view of a safety perspective a SIS can be evaluated by some important safety parameters such as PFD, PFH, MTTF (Mean Time To Failure). And other parameters like STR,  $MTTF_{Spurious}$ , PFS (Probability of Failure Safe) are commonly calculated for a SIS with availability perspective. While the safety integrity levels (SIL) are defined in the standard IEC 61508 [1] to provide a measure of how often a function fails to operate when required (Table 1), spurious trip levels (STL) are defined in [5], [6] to measure how often a function is carried out when not required (Table 2). The more financial damage the spurious trip can cause, the higher the STL of the safety function should be.

Table 1. Safety Integrity Level [1]

SIL	PFD <sub>avg</sub>	PFH
1	$\geq 10^{-2}$ to $< 10^{-1}$	$\geq 10^{-6}$ to $< 10^{-5}$
2	$\geq 10^{-3}$ to $< 10^{-2}$	$\geq 10^{-7}$ to $< 10^{-6}$
3	$\geq 10^{-4}$ to $< 10^{-3}$	$\geq 10^{-8}$ to $< 10^{-7}$
4	$\geq 10^{-5}$ to $< 10^{-4}$	$\geq 10^{-9}$ to $< 10^{-8}$

Table 2. Spurious-Trip Level<sup>TM</sup> [5], [6]

STL	Probability of Fail Safe Per Year	Spurious-Trip Cost
X	$\geq 10^{-(x+1)}$ to $< 10^{-x}$	...
...	...	...
5	$\geq 10^{-6}$ to $< 10^{-5}$	10M€ - 20M€
4	$\geq 10^{-5}$ to $< 10^{-4}$	5M€ - 10M€
3	$\geq 10^{-4}$ to $< 10^{-3}$	1M€ - 5M€
2	$\geq 10^{-3}$ to $< 10^{-2}$	500k€ - 1M€
1	$\geq 10^{-2}$ to $< 10^{-1}$	100k€ - 500k€

The SIS reliability is analyzed by different methods, like reliability block diagrams [2], Markov models [3], approximation formulas [8], etc. Most of the references focus on low-demand systems and do not take high-demand systems into consideration as well as the borderline between two SIS types. Some authors suggest to incorporate the rate of demands into the analysis by using the Markov model [11], [8], [12]. However, H. Jin, M.A Lundteigen and M. Rausand [10] listed some criterion in the quantification of the SIS reliability performance (PFD and PFH) and presented

modelling issues for this quantification for both demand modes. Issues like demand rate, demand duration make the difference between low-demand and high-demand systems. The borderline between these system modes is discussed and shown by the quantification of SIS reliability with Markov modelling [10], [13]. But this borderline has not been considered for the evaluation of a SIS from an availability perspective. STR and  $MTTF_{Spurious}$  have been commonly calculated for a low-demand system.

The main purpose of this article is to verify the difference between low-demand and high-demand systems for de-energized to trip application by using the block diagram and the Markov method for the STR and  $MTTF_{Spurious}$  calculation. This paper is organized as follows: section 2 discusses the definition and causes as well as the characteristics of spurious activation. In section 3 the differences between low-demand and high-demand systems are described. In the next section, section 4, the evaluation of spurious trip rate and  $MTTF_{Spurious}$  of these system modes is studied for 1001 systems. The analysis is based on block diagram and Markov model. And finally, a discussion on the overall study is provided in Section 5.

## 2 Spurious Trip

A spurious trip is one cause of an unexpected plant shutdown initiated by a safety-instrumented system. Namely, if a safety loop component fails to function, the safety instrumented system is prompted to shut down that part of the plant's operation. This is done because the failure of a particular safety loop can prevent the safety-instrumented system from functioning properly. It does not guarantee plant safety. Therefore, spurious activation normally leads to lost production or low availability of the EUC [9].

Industry data report that when a process unit experiences a high number of spurious alarms, the operators become ambivalent and are likely to respond slowly or not at all to a critical "real alarm" [7]. This means that spurious trip is not only expensive, but also in most cases can be considered as dangerous too. The standard IEC 61508 has no requirement related to spurious activations, while IEC 61511 requires that a maximum STR is specified, but the standard does not provide how the rate should be estimated [1], [4] and [9].

## 2.1 Spurious Trip Rate

The spurious trip rate or also known as “false trip rate” is defined in [3]: “the term spurious trip rate (STR) refers to the rate at which a nuisance or spurious trip might occur in the SIS”. The unit of STR is 1/h and describes how available a component or a system is. The availability is higher if the STR is smaller.

To estimate the STR, the oil and gas industry often use the formulas presented in [3] and [8]. When comparing these formulas, it becomes evident that there is no unique interpretation of the concept of spurious trip. While the PDS method [8] defines a spurious trip as “a spurious activation of a single SIS element or of a SIF”, ANSI/ISA-TR84.00.02-2002 [3] refers to a spurious trip as a “non-intended process shutdown”. As a result, the concept of spurious trip is rather confusing and it is difficult to compare the STR in different applications [9]. STR formulas of some conventional methods are presented in the following table:

Table 3. Spurious Trip Rate formulas of conventional method

	ANSI/ISA TR84.00.02-2002 [3]	PDS-Methode [8]	Machleidt & Litz [16]
1001	$STR = \lambda_S + \lambda_{DD} + \lambda_F^S$	$STR = \lambda_{STU}$	$STR = \lambda_{sp} = \lambda_S$
1002	$STR = 2(\lambda_S + \lambda_{DD}) + \beta(\lambda_S + \lambda_{DD}) + \lambda_F^S$	$STR = 2 \cdot \lambda_{STU}$	$STR = (2 - \beta_{sp}) \lambda_{sp}^{1002}$ $\lambda_{sp}^{1002} = \sqrt{\lambda_{sp1} \lambda_{sp2}}$
2002	$STR = 2\lambda_S(\lambda_S + \lambda_{DD})MTTR + \beta(\lambda_S + \lambda_{DD}) + \lambda_F^S$	$STR = \beta \cdot \lambda_{STU}$	
2003	$STR = 6\lambda_S(\lambda_S + \lambda_{DD})MTTR + \beta(\lambda_S + \lambda_{DD}) + \lambda_F^S$	$STR = C_{2003} \beta \lambda_{STU}$	$STR = \beta_{sp} \lambda_{sp}^{2003}$ $\lambda_{sp}^{2003} = \sqrt{(\lambda_{sp1} \lambda_{sp2}) + \lambda_{sp1} \lambda_{sp3} + \lambda_{sp2} \lambda_{sp3}} / \sqrt{3}$
2004	$STR = 12(\lambda_S + \lambda_{DD})^3 MTTR^2 + \beta(\lambda_S + \lambda_{DD}) + \lambda_F^S$	$STR = C_{3004} \beta \lambda_{STU}$	

## 2.2 Probability of Spurious Trip

Probability of Failure Spurious (PFS) is the probability of failure due to the spurious trip. The smaller this value, the more available the system is. For the evaluation and comparison of systems, the average PFS<sub>avg</sub> is calculated as followed:

$$PFS_{avg}(T) = \frac{1}{T} \int_0^T PFS(t) \cdot dt \quad (1)$$

$$= \frac{1}{T} \int_0^T (1 - R_{Spurious}(t)) \cdot dt$$

with  $R_{Spurious}(t)$  is calculated by the following equation:

$$R_{Spurious}(t) = e^{-\int_0^t STR(\tau) d\tau} \quad (2)$$

## 2.3 Mean Time To Failure Spurious

Mean Time to Failure Spurious is abbreviated as  $MTTF_{Spurious}$  and is the estimated time between spurious failures of a component or a system [3]. To estimate the  $MTTF_{Spurious}$  value, ISA [3] introduces three methods: simplified equation, fault tree analysis and the Markov model.  $MTTF_{Spurious}$  is proportional to the availability. This means that a component or a system is more available if the  $MTTF_{Spurious}$  value is higher. The following equation presents the calculation of  $MTTF_{Spurious}$  by simplified equation:

$$MTTF_{Spurious} = \int_0^{\infty} R_{Spurious}(t) \cdot dt \quad (3)$$

## 3 Low demand and high demand system

A SIS has to achieve or maintain a safe state for the system. The SIS is protecting with respect to a specific process demand. Safe state can be defined differently for each system. In some cases, the safe state is to maintain before the demand occurs, while in other cases, it means to stop the EUC. Typical low-demand systems are emergency shutdown systems (ESD), process shutdown systems (PSD) or airbag systems in automobiles. And the typical high-demand systems are railway signal systems, safety-related electrical control systems for machinery. One of the important aspects of SIS with low-demand is that the EUC remains in the safe state after the SIS has responded to a demand. And for a SIS with high-demand the EUC will be returned to the normal operating state after the demand [10]. For example, a railway signaling system is always ready to respond to a new request when the previous train has left the rail section [10].

Another difference between low-demand and high-demand systems is the functional testing. For a low-demand SIS, it is important to perform

functional testing to detect DU-failure (dangerous undetected) but it is not always required for high-demand. Due to the fact that the demand rate is high it may not be possible to use functional testing to detect and repair DU-failures before the next demand. However, it is important to perform regular testing for high-demand systems to prevent the operating of SIS with reduced fault tolerance [10].

The diagnostic testing is an automatic self-test that is implemented in SIS to reveal failure without an interruption of the EUC and it is frequent. It can take place every few seconds, minutes or hours. This test should be carefully considered for the both systems. This means, for low-demand systems, there is usually enough time to repair and restore the function until the next demand appears. But for high-demand systems, the demand rate and the diagnostic test frequency may be the same [10].

The demand rate varies from low to high or continuous and the duration of each demand may vary from short to long period. So, the same equation can usually not be applied to all systems [13]. With the Markov method several authors have shown the best suited for analyzing safety systems. By using this method, it is possible to model different states with different failure modes of the components, different points in time, periods and test strategies. Therefore the authors in [10], [13] have used the Markov model to illustrate the borderline between low-demand and high-demand systems in a better way. The whole calculations of PFD and PFH are dependent on the demand rate and the demand duration. Based on this result and availability theory, a STR-, PFS- and  $MTTF_{\text{Spurious}}$  calculation of the 1oo1 system will be presented in low- and high-demand in this article.

## 4 Modeling of 1oo1 system

If the system fails because of a spurious trip failure, the system will be in de-energized state. This means that the system is not available anymore. The characteristics of 1oo1-architecture will be presented in Fig. 2. The EUC enters a safe state without demand, when a safe failure respectively spurious trip failure occurs in the SIS.

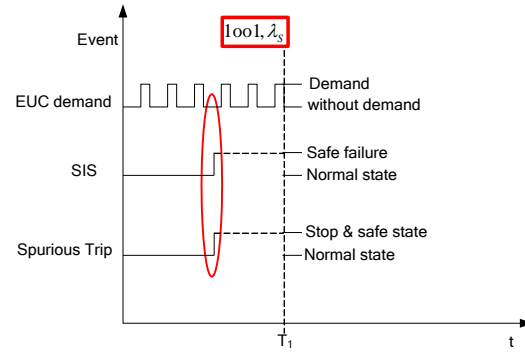


Fig. 2. EUC and SIS of 1oo1 architecture [14]

### 4.1 Block diagram

A block diagram of a SIS with 1oo1-architecture is illustrated in Fig. 3 with three elements: input, logic and output:

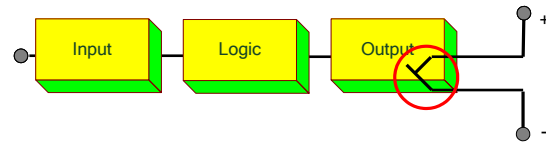


Fig. 3. Block diagram of 1oo1-architecture

A SIS with 1oo1-architecture fails spurious, when a safe failure in SIS or a false demand arises. Therefore, the spurious trip rate consists of not only the rate of safe failures  $\lambda_S$  but also of the demand rate  $\lambda_{DE}$ . Let the factor  $0 \leq \gamma \leq 1$  be the ratio of false demand to total demand of SIS in a considered time interval, the calculation of spurious trip rate for 1oo1 architecture is described in the following way:

$$STR_{1oo1} = \lambda_S + \gamma \cdot \lambda_{DE} \quad (4)$$

$PFD_{\text{avg}_1oo1}$  can be calculated by using simplified equation:

$$\begin{aligned} PFS_{\text{avg}_1oo1} &= \frac{1}{T} \int_0^T PFS_{1oo1}(t) \cdot dt \\ &= \frac{1}{T} \int_0^T (1 - R_{\text{Spurious}_1oo1}(t)) \cdot dt \end{aligned} \quad (5)$$

for 1oo1-architecture the reliability is estimated as follows:

$$R_{\text{Spurious}_1oo1}(t) = 1 - e^{-STR_{1oo1}t} \quad (6)$$

Derived from equations (4), (5) and (6) the formula of  $PFD_{avg}$  for 1oo1-architecture is described as:

$$\begin{aligned} \Rightarrow PFS_{avg\_1oo1}(T) &= \frac{1}{T} \int_0^T (1 - e^{-STR_{1oo1} \cdot t}) \cdot dt \\ &\approx \frac{STR_{1oo1} \cdot T}{2} \\ &\approx \frac{(\lambda_S + \gamma \cdot \lambda_{DE}) \cdot T}{2} \end{aligned} \quad (7)$$

$MTTF_{Spurious\_1oo1}$  can be calculated by:

$$\begin{aligned} MTTF_{Spurious\_1oo1} &= \int_0^{\infty} R_{Spurious\_1oo1}(t) \cdot dt \\ &= \int_0^{\infty} e^{-STR_{1oo1} \cdot t} \\ &= \frac{1}{\lambda_S + \gamma \cdot \lambda_{DE}} \end{aligned} \quad (8)$$

## 4.2 Markov-Modell

By the use of simplified equations the effect of demand rate and demand duration cannot be shown precisely. For this reason Markov model will be used. It is better to model different states with different failure mode of the components. Fig. 4 presents 8 states of the Markov model of a 1oo1-architecture. State Z0 represents the failure free state and the system is operating correctly. From this state, seven other states can be reached:

--State Z1 presents the safe state (de-energized state) or spurious trip state. This state can be left with a transition rate  $\mu_R = 1/\tau_{Repair}$ , with  $\tau_{Repair}$  which is the time the system requires for repair and startup.

--State Z2 has got a safe detected failure and will reach the safe state with the transition rate  $\lambda_{DE}$  when a demand occurs or with the transition rate  $\mu_0 = 1/\tau_{Test}$ , with  $\tau_{Test}$  which is the test time interval.

--State Z3 has got a safe undetected failure. With the transition rate  $\mu_{LT} = 1/\tau_{LT}$  (with  $\tau_{LT}$  which is the lifetime) the system is able to reach the failure free state. And with the transition rate  $\lambda_{DE}$  the system can reach the safe state.

--State Z4 has got a dangerous detected failure. If a demand occurs, the system can reach the

dangerous state Z6 with the transition rate  $\lambda_{DE}$ . And with the transition rate  $\mu_0 = 1/\tau_{Test}$  the system can reach the safe state.

--State Z5 represents the dangerous undetected state. This state can change into state Z0 at the end of its lifetime and subsequently replaced or repaired with a transition rate  $\mu_{LT} = 1/\tau_{LT}$ . If the system is at this state and a demand occurs, the system can reach the dangerous state Z6 with the transition rate  $\lambda_{DE}$ .

--State Z6 is the hazardous state, where the safety function fails and the system cannot reach the safe state.

--State Z7 presents the demand state, where the activation of the safety function is requested.

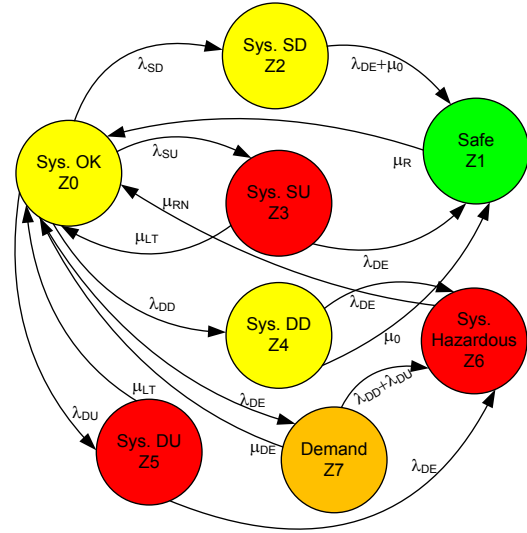


Fig. 4. Markov model of 1oo1-system

The transition matrix is described in the following way:

$$P = \begin{pmatrix} 1 - A_0 & 0 & \lambda_{SD} & \lambda_{SU} & \lambda_{DD} & \lambda_{DU} & 0 & \lambda_{DE} \\ \mu_R & 1 - \mu_R & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \lambda_{DE} + \mu_0 & 1 - A_2 & 0 & 0 & 0 & 0 & 0 \\ \mu_{LT} & \lambda_{DE} & 0 & 1 - A_3 & 0 & 0 & 0 & 0 \\ 0 & \mu_0 & 0 & 0 & 1 - A_4 & 0 & \lambda_{DE} & 0 \\ \mu_{LT} & 0 & 0 & 0 & 0 & 1 - A_5 & \lambda_{DE} & 0 \\ \mu_{RN} & 0 & 0 & 0 & 0 & 0 & 1 - \mu_{RN} & 0 \\ \mu_{DE} & 0 & 0 & 0 & 0 & 0 & \lambda_{DD} + \lambda_{DU} & 1 - A_7 \end{pmatrix}$$

with:

$$A_0 = \lambda_{SD} + \lambda_{SU} + \lambda_{DD} + \lambda_{DU} + \lambda_{DE} \quad (9)$$

$$A_2 = A_4 = \lambda_{DE} + \mu_0 \quad (10)$$

$$A_3 = A_5 = \lambda_{DE} + \mu_{LI} \quad (11)$$

The steady-state equation corresponding to the Markov model in Fig. 4 can be obtained:

$$\begin{aligned} \mu_R P_1 &= (\lambda_{DE} + \mu_0) P_2 + \lambda_{DE} P_3 + \mu_0 P_4 \\ (\lambda_{DE} + \mu_0) P_2 &= \lambda_{SD} P_0 \\ (\lambda_{DE} + \mu_{LT}) P_3 &= \lambda_{SU} P_0 \\ (\lambda_{DE} + \mu_0) P_4 &= \lambda_{DD} P_0 \\ (\lambda_{DE} + \mu_{LT}) P_5 &= \lambda_{DU} P_0 \\ \mu_{RN} P_6 &= \lambda_{DE} (P_4 + P_5) + (\lambda_{DD} + \lambda_{DU}) P_7 \\ (\lambda_{DD} + \lambda_{DU} + \mu_{DE}) P_7 &= \lambda_{DE} P_0 \\ P_0 + P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 &= 1 \end{aligned} \quad (12)$$

Solving this equation system we have:

$$\begin{aligned} A &= \frac{\lambda_{SD}}{\lambda_{DE} + \mu_0} + \frac{\lambda_{SD}}{\mu_R} + \left( \frac{\lambda_{DE}}{\mu_R} + 1 \right) \frac{\lambda_{SU}}{\lambda_{DE} + \mu_{LT}} \\ &+ \left( \frac{\mu_0}{\mu_R} + 1 + \frac{\lambda_{DE}}{\mu_{RN}} \right) \frac{\lambda_{DD}}{\lambda_{DE} + \mu_0} \\ &+ \frac{\lambda_{DU}}{\mu_{LT} + \lambda_{DE}} \left( 1 + \frac{\lambda_{DE}}{\mu_{RN}} \right) + \left( 1 + \frac{\lambda_D}{\mu_{RN}} \right) \frac{\lambda_{DE}}{\mu_{DE} + \lambda_D} \end{aligned} \quad (13)$$

$$P_0 = \frac{1}{A} \quad (14) \square$$

$$P_1 = \frac{(\lambda_{DE} + \mu_0) P_2 + \lambda_{DE} P_3 + \mu_0 P_4}{\mu_8} \quad (15)$$

$$P_2 = \frac{\lambda_{SD} P_0}{\mu_{21}} = \frac{\lambda_{SD} P_0}{\lambda_{DE} + \mu_0} \quad (16)$$

$$P_3 = \frac{\lambda_{SU} P_0}{\mu_{31}} = \frac{\lambda_{SU} P_0}{\lambda_{DE} + \mu_{LT}} \quad (17)$$

$$P_4 = \frac{\lambda_{DD} P_0}{\lambda_{DE} + \mu_{41}} = \frac{\lambda_{DD} P_0}{\lambda_{DE} + \mu_0} \quad (18)$$

$$P_5 = \frac{\lambda_{DU} P_0}{\lambda_{DE} + \mu_{LT}} \quad (19)$$

$$P_6 = \frac{\lambda_{DE} \left[ \frac{\lambda_{DD} P_0}{\lambda_{DE} + \mu_0} + \frac{\lambda_{DU} P_0}{\mu_{LT} + \lambda_{DE}} \right] + \lambda_D \frac{\lambda_{DE} P_0}{\mu_{DE} + \lambda_D}}{\mu_{RN}} \quad (20)$$

$$P_7 = \frac{\lambda_{DE} P_0}{\lambda_{DD} + \lambda_{DU} + \mu_{DE}} = \frac{\lambda_{DE} P_0}{\mu_{DE} + \lambda_D} \quad (21)$$

The  $PFS_{1001}$  value is the sum of the probabilities  $P_1$  and  $\gamma \cdot P_7$ :

$$PFS_{1001} = P_1 + \gamma \cdot P_7 \quad (22)$$

The spurious trip rate of 1001-system will be given by the following equation:

$$\begin{aligned} PFS_{1001} &= 1 - R_{Spurious\_1001}(t) \\ &= 1 - e^{-STR_{1001} \cdot t} \\ \Rightarrow STR_{1001} &= - \frac{\ln(1 - PFS_{1001})}{t} \end{aligned} \quad (23)$$

And the Mean Time To Failure Spurious is calculated as follows:

$$\begin{aligned} MTTF_{Spurious\_1001} &= \int_0^{\infty} R_{Spurious\_1001}(t) \cdot dt \\ &= \int_0^{\infty} e^{-STR_{1001} \cdot t} dt \\ &= \frac{1}{STR_{1001}} \\ &= \frac{-t}{\ln(1 - PFS_{1001})} \end{aligned} \quad (24)$$

The following parameters will be used as an example for an estimation of the parameters of spurious trip failure:

$$MTTR = 8h \Rightarrow \mu_R = \frac{1}{MTTR} = \frac{1}{8}$$

$$S = 0,5$$

$$DC = 0,9$$

$$\tau_{Test} = 24h \Rightarrow \mu_0 = \frac{1}{\tau_{Test}} = \frac{1}{24}$$

$$\beta_D = 0,01$$

$$\beta = 0,02$$

$$\lambda_B = 5 \cdot 10^{-6}$$

$$T = 8760h$$

$$\lambda_{DE} = [10^{-8} \quad 10^{-6} \quad 10^{-4} \quad 10^{-2}]$$

$$\mu_{DE} = [10^{-4} \quad 10^{-3} \quad 10^{-2} \quad 10^{-1}]$$

$$\mu_{RN} = 10^{-6}$$

$$\gamma = 0,01$$

The following Figures (Fig. 5, Fig. 6 and Fig. 7) show the functions of  $PFS_{1001}$ ,  $STR_{1001}$  and  $MTTF_{Spurious\_1001}$  in dependence on demand rate, which are deviated from Markov model in this work. At first, we study the effect of varying demand rate on the  $PFS_{1001}$  (Fig. 5). The  $PFS_{1001}$  function will increase, when the demand rate or demand duration increases. The  $PFS_{1001}$ -value will

reach STL 4 when the demand rate is low and reach STL 2 when demand rate is high.

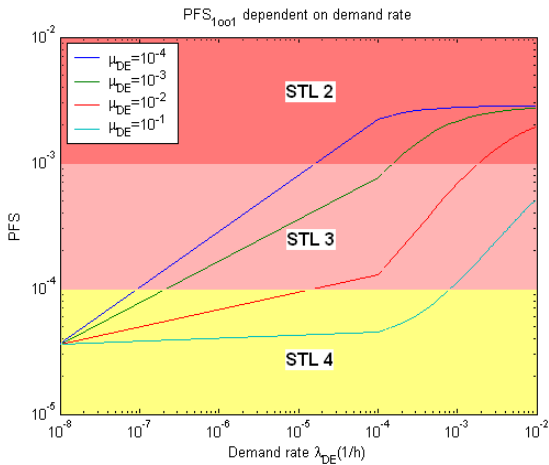


Fig. 5. PFS with different demand rate of 1001-system

Fig. 6 describes the function of  $STR_{1001}$  which depends on the demand rate. Like the  $PFS_{1001}$  function, the  $STR_{1001}$  function will decrease when the demand rate or demand duration decrease. With a low demand rate the function of  $STR_{1001}$  decreases slightly, But with a high demand rate the difference of  $STR_{1001}$  is shown explicitly.

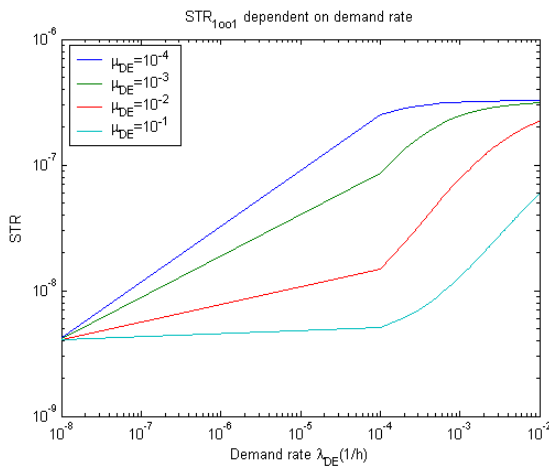


Fig. 6. STR with different demand rate of 1001-system

The  $MTTF_{Spurious\_1001}$  function is shown in the Fig. 8.  $MTTF_{Spurious\_1001}$  value increases when the demand rate or demand duration decreases.

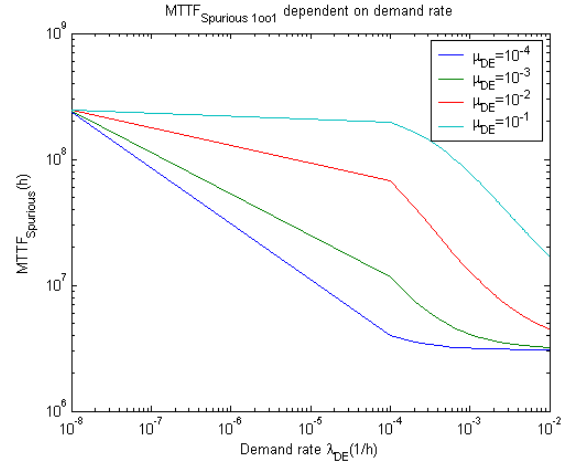


Fig. 7.  $MTTF_{Spurious}$  with different demand rate of 1001-system

Fig. 8 shows the function of  $STR_{1001}$  in dependence on diagnostic coverage factor DC with different methods. The function of  $STR_{1001}$  by method of Machleidt & Litz [16] is like the function of  $STR_{1001}$  by the reliability block diagram method, which is deviated from this work.  $STR_{1001}$  function by ANSI/ISA TR84.00.02-2002 [3] is over another functions.

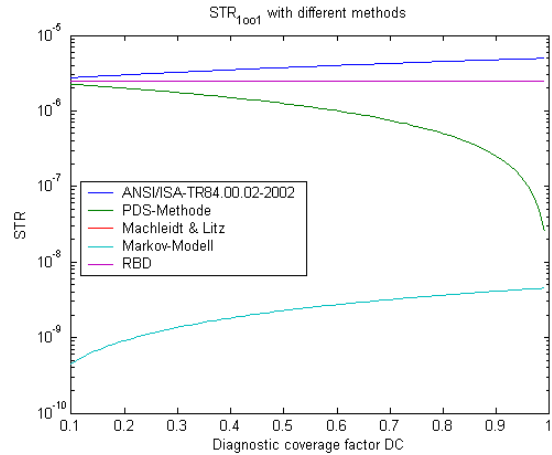


Fig. 8. STR with different demand rate of 1001-system

## 5 Conclusion

This article has analyzed the relationship between SIS reliability and demand rate, as well as the demand duration for 1001 system. Finally, the Markov model provides better ways to analyze this relationship than the block diagram. Therefore, we can say that it is not always possible to use a common formula of reliability calculation for all systems. PFS values are not equal to all systems: low demand and high demand. The same is true for

STR and  $MTTF_{\text{Spurious}}$ . This is based on the recent revision of IEC 61508.

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